AD-E400 647

CONTRACTOR REPORT ARLCD-CR-81017

HIGH FRAGMENTATION STEEL PRODUCTION PROCESS

Colin C. MacCrindle
Metallurgical Engineer
Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant
Scranton, PA 18505

William Sharpe
Project Engineer
ARRADCOM, Dover, NJ 07801

August 1981

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

ERRATA

P. 18	Fig. 2	Add: Magnification = 500x
P. 19	Fig. 3	Add: Magnification = 500x
P. 20	Fig. 4	Add: Magnification = 500x
P. 23	Para. 3	Change: "old inclusion" to "odd inclusion"
P.208	Fig. H3	Change: "Billet 20" to "Billet 2C"

unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER Contractor Report ARLCD-CR-81017	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) High Fragmentation Steel Production Process		5. TYPE OF REPORT & PERIOD COVERED Final Engineering Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Colin MacCrindle, Metallurgical Engineer Chamberlain Manufacturing Corporation William Sharpe, Project Engineer, ARRADCOM		8. CONTRACT OR GRANT NUMBER(s) DAAA09-74C-4009
9. PERFORMING ORGANIZATION NAME AND ADDRESS Chamberlain Manufacturing Corporation Scranton Army Ammunition Plant 156 Cedar Avenue Scranton, PA 18501		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS MM&T Project No: 5794189
11. CONTROLLING OFFICE NAME AND ADDRESS ARRADCOM, TSD STINFO DIV (DRDAR-TSS) Dover, N.J. 07801		12. REPORT DATE August 1981
		13. NUMBER OF PAGES 342
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) ARRADCOM, LCWSL Munitions Systems Div. (DRDAR-LCU-M) Dover, N.J. 07801		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This project was accomplished as part of the U.S. Army manufacturing technology program. The primary objective of this program is to develop on a timely basis, manufacturing processes, techniques, and equipment for use in production of Army materiel.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

HF-1 Steel
Metallurgical Evaluation
MMT-Process improvement

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Two heats of BOF HF-1 steel were purchased, one from Republic Steel and one from Bethlehem Steel. Essential steel manufacturing information was obtained for future reference. Both heats were metallurgically characterized with respect to microstructure, macrostructure, cleanliness, segregation, hardness, and obtainable tensile properties.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

SECURITY CLASSIFICATION OF THIS PAGE(*When Data Entered*)

SECURITY CLASSIFICATION OF THIS PAGE(*When Data Entered*)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES

INTRODUCTION

The production of high fragmentation steel to date has been problematic and uneconomical. The purpose of this project is to investigate and report on the refinement of production processes and techniques in order to reduce costs and yield a quality product for use in the production of projectile metal parts.

Problems encountered with HF-1 include excessive machining requirements in trepanning the boattail areas of projectiles, high energy requirements in the spheroidize anneal of forgings, two-hit nosing operations requiring intermediate stress relief, inability of heat treatments to impart both mechanical properties and the toughness needed to meet drop test requirements, and steel anomalies. It is the purpose of this project to investigate and correct these problem areas in three phases, the first of which is the subject of this report.

This first phase consists of two tasks: the purpchase of HF-1 steel (Task A); and its metallurgical evaluation (Task B); as described below.

Task A. Purchase of HF-1 Steel, MIL-S-50783

Contractor shall purchase one heat of HF-1 Steel of approximately 150 tons from each of two separate suppliers. Steel shall be manufactured by the basic oxygen furnance (BOF) method, and shall be in suitable round corner squared (RCS) size for fabrication into 155-mm M549 projectiles by contractor processes. All bars shall have been marked as to heat, ingot, and location within that ingot. Note that this identification shall be kept on all steel throughout its processing cycle.

At a minimum, each supplier shall have a steel bar from three ingots per heat slow-cooled from under the lower critical --by methods not using a furnace. Material shall be comprised of the first and last usable ingots and an ingot approximately from the middle of the melt. Cooling method envisioned is one that the steel industry would have to institute should an overcapacity situation exist for alloy steel, i.e., where cooling facilities would be inadequate for quantity of steel being rolled (such as mobilization).

Task B. Characterization of Steel Supplied

The three ingots from each heat, along with material from the three ingots adjacent to them, and cooled by conventional furnace method, shall receive metallurgical evaluation by the contractor. As a minimum, these evaluations shall include chemistry, cleanliness (as per ASTM-E-45, Microscopical Methods, Method C), segregation, and macro and micro quality. Surface quality of all incoming material shall also receive characterization with regard to laps, seams, etc. Comparisons shall be made between heats, cooling techniques, and location within the heat.

Material from all six ingots, previously mentioned from each heat, shall have a minimum of three Jominy End Quench specimens machined and tested as per ASTM-A-255 to determine the ability of steel to harden. Then using the information obtained a minimum of five longitudinal and transverse coupons each shall be subjected to an austenitize, quench and temper heat treatment designed to result in material with a minimum yield strength of 120,000 psi and a minimum elongation of 12%. Longitudinal coupons shall have a minimum thickness of base. Tensile specimens shall be machined from these coupons and mechanical property results shall be obtained and correlated with Jominy data.

Contractor shall retain remaining steel in anticipation of second year optimization efforts.

It should be noted here that the steel from Republic does not fully comply with SOW MFX-001. Republic uses only slow-cooling in the production of HF-1. This situation was brought to the attention of the government by Chamberlain Manufacturing Corporation's letter of 28 August 1979, and the purchase of Republic's HF-1 was subsequently approved. Since one of the objects of this project was to obtain data on alternate slow cooling processes, Republic's method satisfies the intent of the SOW.

TASK A: PURCHASE OF STEEL*

Republic

Heat 8068860 of HF-1 steel was produced in Masland, Ohio on 12/17/79, in accordance with MIL-S-50783. The heat consisted of 161553 kg (356,163 lbs.) of HF-1 at a cost of $95,902.81. Colin MacCrindle, Chamberlain Manufacturing Corporation Metallurgical Engineer, was present during processing.

Tap (fig. B1): 200 tons of 100% scrap are melted in an electric furnance and finished as BOF quality steel.

Pour (fig. B2): Forty (40) hot top ingots (25 x 27 inches) are poured at 1515°C (2750°F) along with a cast jominy bar.

---

* All figures referred to in this section are found in Appendix B.

Soak (fig. B3): The ingots are then soaked at 1120°C (2050°F) for eight hours and a shrinkage of approximately six inches is cropped from the top.

Reduce (fig. B4-5): The ingots are then reduced through a series of thirteen passes at a rate of 7% to 15% per pass on a 35 inch blooming mill, to 10 x 8 3/4 inches.

Crop Ends: Both ends are cropped square.

Cool: Pit cool.

Segregation: A two inch cross section is cut and etched with 50% sulfuric acid. The segregation is then evaluated in accordance with ASTM-E-381. For this heat, the macro etch was taken from the top, middle, and bottom of each first, middle and last ingot.

Anneal and Cool: The blooms are pit-annealed at 1120°C (2050°F) and pit-cooled.

Grind (fig. B6): The blooms are then surface ground on all four sides to remove surface defects.

Re-heat (fig. B7): Re-heating to 1090°C (2000°F) is accomplished in a pusher-type furnace at the 18 inch mill.

Reduce (fig. B8): This operation is done on a seven pass reversing mill in which reduction proceeds from 10 x 8 3/4 to 9 x 8 to 8 x 8 to 8 x 7 to 7 x 6 to 6 x 6 to 6 x 5 1/4 inches.

Final Size (fig. B9): A final size of approximately 5 1/4 x 5 1/4 inches is accomplished on a single pass finishing stand.

Crop: A six inch crop is taken from the leading edge of each billet.

Saw: The billets are hot sawn to equal mult size of 47.8 kg. (105.5 lbs.).

Stamp Identification: Each end of each billet is stamped with aircraft quality steel identifcation in accordance with the Scope of Work (Table 1).

Preliminary Cooling (fig. B10): The billets are run out on a preliminary cooling bed before the next operation.

Pit Cool (fig. B11): Final cooling is accomplished by placement of the billets in a pit to slow cool from approximately 650°C (1200°F) for seventy-two hours.

Steel made by this process is termed to be double converted.

TABLE 1. Standard Identification Of Steel

AIRCRAFT QUALITY STEEL

NUMERALS INDICATE INGOTS ROTATION POURED NOT TO BE USED FOR ANY OTHER STAMPING
LETTERS " CUTS FROM TOP TO BOTTOM

NOTE:
ALL STAMPING MUST BE ON TOP END OF ALL CUTS
THIS APPLIES TO BLOOMING MILLS
BAR MILLS
HEAT TREAT (WHEN COLD SAWING MATERIAL TO LENGTH)

EXAMPLE:
FOUR INGOTS CAST ON A HEAT - EACH INGOT ROLLED TO TWO CUTS
STAMPING WILL BE AS FOLLOWS:

TOP END OF INGOT

1A	1B
2A	2B
3A	3B
4A	4B

BUTT END OF INGOT

LAMBERTON MILL ROLLING

ASSUME EACH BLOOM ROLLED AND CUT IN FOUR
TAKE BLOOM 2B FOR EXAMPLE:

TOP END OF 2B BLOOM

2BA	2BB	2BC	2BD

NOTE:
THERE MAY BE ANOTHER CASE WHERE A FURTHER SUB-DIVISION IS NECESSARY;
(THIS HOWEVER WILL BE VERY RARE AS WHERE MATERIAL GOES TO COLD SAWS IT IS GENERALLY NOT CUT TO LENGTH AT LAMBERTON AND THE COLD SAWS SIMPLY STAMP THE LAMBERTON CUT NUMBERS.)

WHENEVER IT OCCURS ANOTHER SERIES OF CUT-LETTERS MUST BE ADDED MAKING ONE NUMERAL AND THREE LETTERS IN THE IDENTIFICATION MARK.
FOR EXAMPLE ASSUME THE CUT 2BC ABOVE IS COLD SAWED INTO FOUR PIECES:

TOP END OF 2BC

2BCA	2BCB	2BCC	2BCD

5961-26

REPUBLIC STEEL CORP.
CENTRAL ALLOY DISTRICT

Bethlehem

Heat 17K4209 was produced by Bethlehem Steel at Lackawanna, New York on 1/25/80. D. Covey, Quality Control Manager of Chamberlain Manufacturing Corporation, and W. Sharpe of ARRADCOM were present. 185973 kg (410,000 lbs.) of steel were produced at a cost of $81,658.52.

Tap (fig. B12): a 200 ton BOF heat of 30% scrap and 70% hot metal was poured into a BOF and tapped at 1590°C (2900°F).

Pour (fig. B13): 20 ingots, 30 x 35 inches, weighing 9299 kg (20,500 lbs.) each are teemed from a bottom pour ladel.

Cool and Strip (fig. B14): After cooling the hot topped ingots are stripped from the molds.

Equalize: Billets are heated to 910°C (1675°F) and homogenized for 18 hours.

Soak (fig. B15): The equalized billets are now heated to 1200°C (2200°F) to prepare for rolling.

Roll (fig. B16): Seventeen passes with 11.5% reduction are required to reduce the steel on a 44 inch blooming mill. There is 11% top and 5% bottom discard.

Scarf (fig. B17): All blooms are hot scarfed.

Roll (fig. B18): Intermediate size is achieved on the 30 inch billet mill.

Reheat (fig. B19): Due to excess cooling the billets are soaked at 1200°C (2200°F) for one hour.

Finish Size (fig. B20): The billets are now reduced to the finished size of approximately 5 1/4 x 5 1/4 inches on the 21 inch billet mill, producing 10 billets per bloom, including 12 shorts.

Transfer to hot bed and identify (fig. B21): Identification of all full length product is accomplished with each ingot bearing a sequential numerical marker and each billet bottom end identified as X (bottom), I, (I), H, (H), (C), C (middle), (B), B, and T (top). Shorts were identified as T and represent the top billet per ingot number.

Bung Cool (fig. B22): Billets from ingots 2 thru 9, and 11 thru 19 were bung furnance cooled from 700°C (1300°F).

Alternate (Slow) Cool (fig. B23): Billets from ingots 1, 10, and 20 were charged into a cooling box as an alternate slow cooling process.

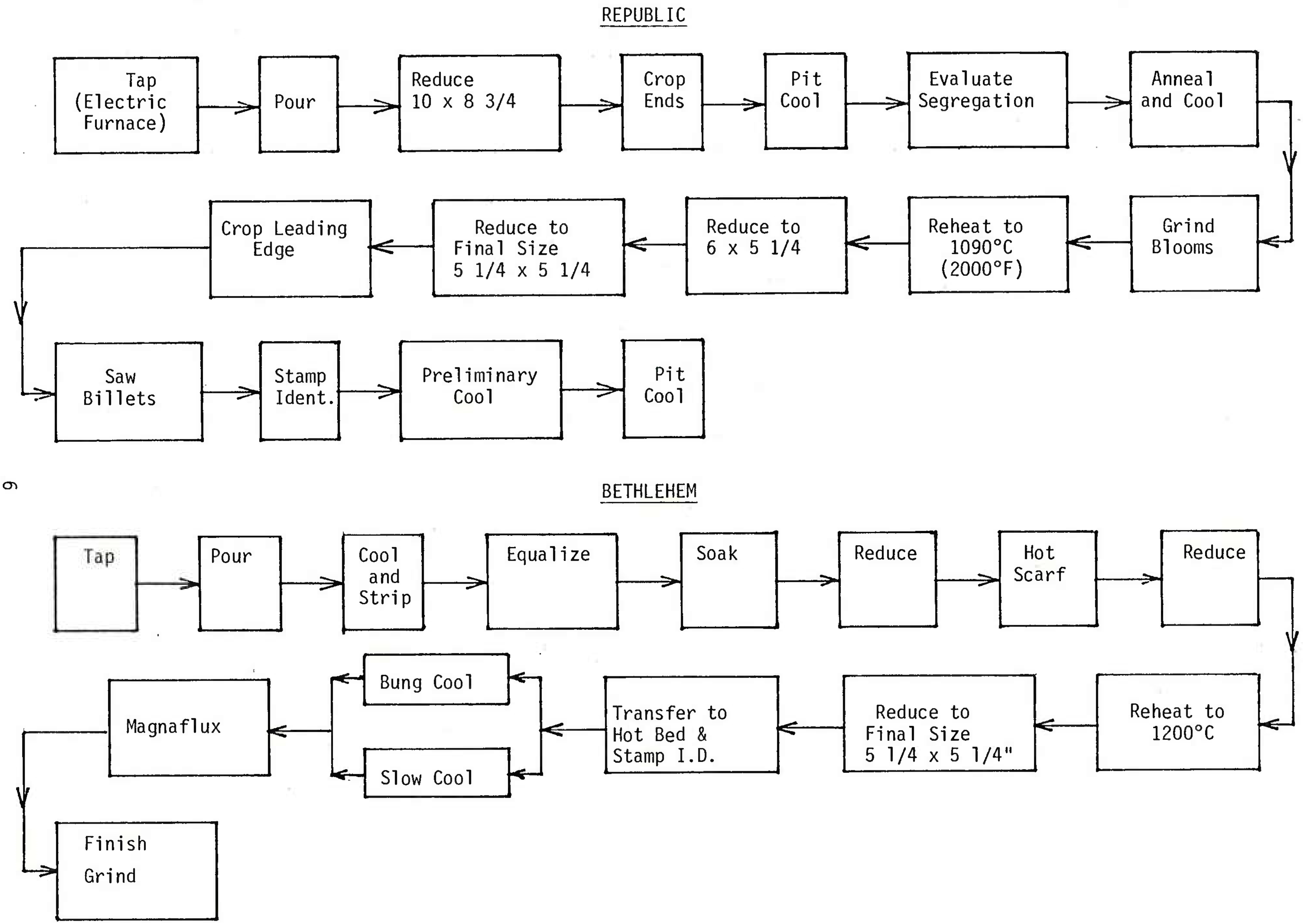


Figure 1 : Republic Steel Production Process (double converted) versus Bethlehem Steel Production Process (single converted)

Inspect (fig. B24): After cooling, all billets are Magnafluxed for surface defect detection.

Grind (fig. B25): Surface defects detected in the previous operation are eliminated with a surface grinder.

Identifications:

Comparison of Process

A flow-charted comparison of the Republic and Bethlehem processes may be seen in figure 1.

TASK B. CHARACTERIZATION OF HF-1

Surface Quality

A representative photograph of Republic's HF-1 is included as figure B26. It can be seen from this photograph that the billets are straight and show little surface grinding. Bethlehem's HF-1, as seen in figures B27 and B28, exhibits evidence of considerable surface grinding to condition the billet. It appears that Republic's conditioning in the mill, before subsequent reduction, accounts for the significant difference in final conditioning.

Republic's hot sawed ends are shown in figures B29 and B30. Hot sawing produces a relatively smooth face which is square, whereas Bethlehem's hot-sheared ends (figures B31 and B32) are rough and out-of-square.

A possible consequence of the hot shear method involves entry into the die pot or cavity. Problems could arise here, because of the out-of-square ends.

Dimensions

The specifications of HF-1 issued by Chamberlain Manufacturing Corporation called for a diagonal measure of 6.8 + 0.090 - 0.060 inches. Figures C1 through C6 illustrate the actual measurements, all of which meet the specifications and are included in appendix C.

No problems are expected because of billet size or shape, save the previously mentioned hot-sheared end configuration.

Metallurical Evaluation

Heat Chemistry

Each of the suppliers of HF-1 submitted a chemical analysis of their product.

The ordering specifications are shown in table 2. They are given as percentages of total composition.

TABLE 2. Chemical specifications for HF-1 steel

	C	Mn	P	S	Si	Ni	Cr
Min	1.00	1.60	---	---	0.70	---	---
Max	1.15	1.90	0.035	0.040	1.00	0.25	0.20

	Mo	Cu	Al
Min	---	---	---
Max	0.60	0.35	0.020

Both heats were delivered within specifications as shown in tables 3 and 4, below.

TABLE 3. Ladle analysis of heat 8068860 (Republic)

C	Mn	P	S	Si	Ni	Cr	Mo	Cu	Al
1.05	1.74	.010	.016	.81	.12	.17	.03	.21	.004

TABLE 4. Ladle analysis of heat 517K4209 (Bethlehem)

C	Mn	P	S	Si	Ni	Cr	Mo	Cu	Al
1.11	1.74	.028	.013	.82	.02	.06	.011	.020	.005

Billet Chemistry

For ease of reference, tables 5 and 6 are a composite of each supplier's billet chemistry analysis compared with U.S. Testing Company's analysis of that heat.

Both vendors derived their chemistry ratings from mid-radius samples; whereas U.S. testing analyzed edge samples taken from 1/8 inch below the surface of the billet. Republic is higher in sulfur, nickel, chromium, molybdenum, and copper contents; whereas Bethlehem has more carbon, phosporous, and silicon. The relevance of the lower levels of chromium and nickel in the Bethlehem HF-1 are discussed elsewhere, in conjunction with hardenability.

U.S. Testing was sent edge samples for chemical analysis so that the edge chemistry 0.25 inches beneath the surface could be compared with the chemistry analysis of the steel mill which is taken at mid-radius.

U. S. Testing Company reported higher levels of chromium and copper than Bethlehem, for the subject heat (Table 6). Both laboratories were instructed to perform check analysis on their data and both replicated their original results. The Bethlehem values appear to be correct in the light of hardenability values (see below).

Edge versus Mid-radius

TABLE 5. Chemistry, heat 8068860, Republic (mid-radius) versus U. S. testing (edge)

		C		Mn		P		S		Si	
		Rep	UST	Rep	UST	Rep	UST	Rep	UST	Rep	UST
	TOP	1.04	1.09	1.70	1.63	0.009	.016	0.019	0.012	0.82	0.83
1	MID	1.04	0.96	1.72	1.63	0.008	.004	0.018	0.009	0.80	0.81
	BOT	1.04	1.09	1.71	1.62	0.016	.006	0.017	0.016	0.83	0.86
	TOP	1.04	1.02	1.73	1.63	0.010	.013	0.016	0.013	0.81	0.82
20	MID	1.03	0.93	1.72	1.62	0.008	.013	0.017	0.019	0.82	0.82
	BOT	1.04	1.10	1.73	1.68	0.009	.009	0.018	0.019	0.80	0.84
	TOP	1.03	1.12	1.78	1.68	0.011	.008	0.016	0.007	0.80	0.75
40	MID	1.04	1.08	1.76	1.67	0.008	.010	0.017	0.012	0.80	0.80
	BOT	1.05	0.95	1.76	1.64	0.011	.010	0.017	0.026	0.81	0.84
	Mean	1.04	1.04	1.74	1.64	0.010	.010	0.017	0.015	0.81	0.82

		Ni		Cr		Mo		Cu		Al	
		Rep	UST	Rep	UST	Rep	UST	Rep	UST	Rep	UST
	TOP	0.12	0.14	0.17	0.16	0.03	.03	0.21	0.18	0.005	<.005
1	MID	0.12	0.12	0.17	0.17	0.03	<.01	0.20	0.12	0.006	.005
	BOT	0.12	0.11	0.17	0.16	0.03	.03	0.20	0.14	0.005	.005
	TOP	0.12	0.11	0.17	0.15	0.03	.02	0.20	0.17	0.004	.005
20	MID	0.12	0.12	0.17	0.15	0.03	.01	0.20	0.17	0.005	.005
	BOT	0.12	0.14	0.17	0.15	0.03	.03	0.20	0.18	0.003	.005
	TOP	0.12	0.13	0.17	0.16	0.03	.04	0.21	0.17	0.003	.005
40	MID	0.12	0.12	0.17	0.15	0.03	.03	0.20	0.18	0.006	.005
	BOT	0.12	0.14	0.17	0.16	0.03	.03	0.20	0.17	0.005	.005
	Mean	0.12	0.125	0.17	0.156	0.03	.025	0.20	0.164	0.005	.005

TABLE 6. Chemistry, heat #517K4209, Bethlehem (mid-radius) versus U.S. testing (edge)

		C		Mn		P		S		Si	
		Beth	UST	Beth	UST	Beth	UST	Beth	UST	Beth	UST
1	TOP	1.12	1.08	1.74	1.63	0.027	0.021	0.012	0.015	0.77	0.78
	MID	1.14	1.10	1.77	1.68	0.028	0.023	0.014	0.017	0.88	0.88
	BOT	1.11	1.14	1.74	1.69	0.026	0.022	0.013	0.012	0.75	0.80
2	TOP	1.11	1.02	1.72	1.61	0.028	0.017	0.012	0.015	0.81	0.86
	MID	1.08	1.18	1.72	1.68	0.029	0.023	0.010	0.010	0.86	0.87
	BOT	1.09	1.25	1.73	1.69	0.025	0.026	0.012	0.012	0.83	0.80
10	TOP	1.13	1.15	1.74	1.69	0.024	0.019	0.012	0.005	0.79	0.76
	MID	1.13	1.01	1.78	1.69	0.029	0.024	0.014	0.012	0.84	0.78
	BOT	1.09	0.99	1.73	1.65	0.025	0.023	0.013	0.016	0.79	0.81
11	TOP	1.13	0.94	1.73	1.64	0.031	0.027	0.016	0.014	0.84	0.74
	MID	1.13	1.29	1.76	1.63	0.027	0.020	0.012	0.007	0.87	0.75
	BOT	1.10	1.15	1.72	1.64	0.027	0.018	0.013	0.007	0.82	0.80
19	TOP	1.13	0.92	1.72	1.71	0.030	0.007	0.013	0.003	0.82	0.86
	MID	1.11	1.15	1.71	1.68	0.029	0.022	0.012	0.003	0.87	0.86
	BOT	1.08	1.05	1.74	1.68	0.029	0.025	0.011	0.014	0.81	0.80
20	TOP	1.14	0.92	1.72	1.60	0.025	0.025	0.014	0.010	0.83	0.86
	MID	1.12	1.13	1.76	1.70	0.028	0.023	0.013	0.028	0.84	0.81
	BOT	1.09	1.10	1.78	1.65	0.025	0.018	0.013	0.017	0.78	0.84
	Mean	1.12	1.08	1.74	1.589	0.0273	0.213	0.0127	0.0114	0.819	0.814

	Ni	Cr	Mo	Cu	Al
Beth	0.02	0.06	0.011	0.020	0.005
UST	0.01-0.03	0.10-0.14	0.01	0.05-0.12	0.005

Note, that only manganese seems to be segregated. It has higher values toward the center. This is consistent for both heats of steel.

Segregation

In order to determine the segregation of HF-1, billet sections from both heats were compared to macrographs in MIL-STD-1459A. Both heats were classified as acceptably sound steel. The macrographs are contained in Appendix D for comparison.

The segregation ratings for the subject steel are shown in tables 7 and 8. The rating system consists of an alpha character and a numeral. A - designates center defects; B - subsurface; C - ring; and D - miscellaneous defects. The numerical designation indicates the severity of the defect, progressing from one to seven, seven being the most severe. Any defect in the D series can be grounds for the rejection of the steel.

The steel was etched in a solution of 50% hydrochloric acid and 50% water after sections were sawed. Upon comparison with the macrograph standards of MIL-STD-1459A, all steel from both heats was rated as clean and sound.

TABLE 7. Segregation evaluation: Republic

Billet			
1TOP	B1	C1	A2
1MID	B1	C1	A2
1BOT	B1	C1	A2
20TOP	B1	C1	A2
20MID	B1	C1	A2
20BOT	B2	C2	A2
40TOP	B2	C1	A2
40MID	B1	C2	A1
40BOT	B2	C2	A1

TABLE 8. Segregation evaluation: Bethlehem

Billet			
1TOP	B2	C2	A2
1MID	B2	C1	A2
1BOT	B1	C1	A1
2TOP	B1	C1	A1
2MID	B1	C2	A2
2BOT	B1	C1	A1
10TOP	B1	C1	A1
10MID	B1	C1	A2
10BOT	B1	C1	A1
11TOP	B2	C1	A2
11MID	B1	C1	A3
11BOT	B1	C1	A1
19TOP	B1	C1	A3
19MID	B1	C2	A2
19BOT	B1	C1	A1
20TOP	B1	C1	A2
20MID	B1	C1	A1
20BOT	B1	C1	A1

Hardenability

The hardenability for each heat was determined by its manufacturer through the end-quench, or Jominy test, which consists of water quenching a 1" test specimen and measuring to what extent it hardens at varying distances, measured in 1/16" increments from the quenched end.

Republic Steel performed Jominy tests on forged Jominy bars. Austenitization temperature was 843°C (1550°F) and quench was performed as specified in ASTM-255, End Quench Hardenability of Steel. Table 9 gives the hardenability assigned to the heat and figures E1 through E10 show the hardenability curves for Republic's HF-1.

Bethlehem ran Jominy Tests on forged billet samples which were normalized at 870°C (1600°F) prior to machining. All samples were 1 3/8 inches round and austenitized at 843°C (1550°F), soaked for one hour and quenched in the manner prescribed by ASTM-255. Table 10 is the hardenability assigned to the heat by Bethlehem and figures E11 through E29 indicate the Jominy curves. They are included as Appendix E.

TABLE 9. Hardenability values

REPUBLIC STEEL CORPORATION
CLEVELAND, OHIO

CUSTOMER ORDER NUMBER AND DATE

SHIPPED FROM

INVOICE NUMBER 303 284

DATE SHIPPED

5 53004 303

CUSTOMER ABBREVIATION

CONTROL CARD

SALES PRODUCT

CHAMBERLAIN MFG CORP

("SHIP TO" SAME AS "SOLD TO" UNLESS OTHERWISE INDICATED)

"P" PARTIAL SHIPMENT "C" COMPLETE SHIPMENT

END QUENCH HARD RC IN 16THS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	18	20	22	24	26	28	30	32
B1	62	62	62	62	62	62	61	60	58	54	48	46	44	43	42	41	40	39	38	37	36	36	35	34
M1	62	62	62	62	62	62	61	59	56	50	46	44	43	42	41	40	39	38	38	37	36	35	34	32
T1	62	62	62	62	62	61	61	60	57	52	48	45	44	42	41	40	39	38	38	37	36	36	36	33
B20	62	62	62	62	62	62	62	60	57	52	48	44	43	42	41	40	39	38	37	36	35	35	34	33
M20	62	62	62	62	62	62	60	60	57	52	47	44	43	41	41	40	39	38	37	37	36	35	35	34
T20	62	62	62	62	62	62	61	59	56	51	47	44	42	41	41	40	38	37	37	36	35	35	34	34
B40	62	62	62	62	62	61	61	60	59	55	50	47	44	44	42	41	39	39	38	36	36	36	35	35
M40	62	62	62	62	62	62	61	60	58	53	48	46	44	42	41	41	39	38	37	36	36	36	34	34
T40	62	62	62	62	62	62	62	60	59	55	51	46	44	42	42	40	39	38	37	36	36	35	34	34
HEAT	62	62	62	62	62	62	61	60	58	52	48	45	44	42	41	40	39	38	37	36	36	35	34	34

Jominy Hardenability

Hardness results on some tests varied erractically from 57 Rc to 59 Rc at J1 through J6. We do not know the cause of this variation.

Test location (top, middle, or bottom of the ingot) had no noticeable influence on hardenability results.

Assigned hardenability of the heat is:

J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J12	J14	J16	J18	J20
58	58	58	58	58	57	55	51	48	47	45	44	42	41	40

J24	J28	J32
38	35	34

Forged billet samples normalized at 1600°F prior to machining to 1 3/8" round were used for all Jominy tests.

All tests were austenitized at 1550°F. Furnace temperature was stablized at 1550°F prior to austenitizing the tests. Tests were kept in the furnace for 1 hour and immediately quenched. All tests were quenched for 20 minutes.

Probe results are shown in Table 10.

TABLE 10. Hardenability values

	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J12	J14	J16	J18	J20	J24	J28	J32
1 Top	57	58	57	57	58	57	55	51	48	46	45	44	42	41	40	40	37	37
2 Top	58	57	57	57	58	57	54	50	47	46	44	43	42	41	40	38	34	34
10 Top	59	58	58	57	57	57	54	50	47	46	44	43	42	41	40	38	38	37
11 Top	58	58	58	58	58	58	55	51	49	48	45	43	42	41	40	38	34	34
19 Top	58	57	57	57	58	56	55	52	48	47	44	44	42	41	40	38	34	35
20 Top	58	59	57	58	58	58	55	50	49	46	45	44	43	42	41	36	35	34
1 Middle	57	59	58	58	58	58	55	52	49	48	45	45	43	41	40	37	37	35
2 Middle	58	58	58	58	59	57	55	50	48	47	45	44	43	41	39	38	36	34
10 Middle	57	56	56	56	57	56	53	49	48	47	45	43	42	42	41	36	35	34
11 Middle	59	58	58	59	59	57	56	52	48	47	46	44	43	41	40	39	36	35
19 Middle	58	58	58	57	58	56	53	50	48	47	46	43	43	42	39	37	35	35
20 Middle	59	57	58	59	58	57	54	49	48	46	45	43	43	41	41	38	37	32
1 Bottom	59	58	58	59	59	58	56	52	49	47	45	44	42	41	40	40	35	33
2 Bottom	58	58	59	59	59	57	54	51	49	47	46	44	43	42	41	38	34	34
10 Bottom	58	57	57	57	57	56	53	50	47	47	45	43	41	41	40	36	35	33
11 Bottom	58	59	58	58	59	58	55	51	48	47	44	43	42	42	40	39	34	32
19 Bottom	59	59	59	58	57	58	56	50	48	48	44	43	42	41	40	38	34	34
20 Bottom	59	57	58	59	59	58	58	56	54	49	46	45	43	42	41	40	37	35

Comparison

The Jominy values for Republic's HF-1 are consistent and regular. The steel hardened to Rc 60 and above from J1 through J8 and maintained uniformity throughout.

The values for Bethlehem are erratic from J1 through J6, ranging from Rc 57 to Rc 59 and are consistently less hardenable than the Republic Steel.

Within each heat, there are no significant differences because of location in the heat, nor are there any significant differences between Bethlehem's Bung and Box Cooled samples.

The previously mentioned low chemistry values for Nickel and Chromium for Bethlehem's HF-1 are supported by the significantly lower hardenability values indicated here.

Billet Cross Section Hardness Patterns

A 10 x 10 grid of 1/2 inch blocks was incribed on the face of sections from each billet. One hundred hardness readings were then taken from each section. Tables 11 and 12 below represent the arithmetic mean of the Rc hardness of each section and its Brinnel Hardness Number. Actual hardness readings are included in Appendix F.

TABLE 11. Hardness pattern - Republic

	Rc (Mean)	BHN
1 TOP	32.409	298
1 MID	32.805	300
1 BOT	38.800	300
20 TOP	33.575	307
20 MID	32.554	299
20 BOT	37.892	348
40 TOP	35.692	327
40 MID	29.696	279
40 BOT	35.728	327

Heat: Mean Rc = 34.35

Billet, Mean Rc:	Location, Mean Rc:
1 = 34.671	TOP = 33.892
20 = 34.673	MID = 31.685
40 = 33.705	BOT = 37.473

TABLE 12. Hardness pattern - Bethlehem

	Cooling Method	Rc (Mean)	BHN
1 TOP		32.888	300
1 MID	Box	30.366	284
1 BOT		29.302	278
2 TOP		30.802	287
2 MID	Bung	25.974	260
2 BOT		24.231	250
10 TOP		30.514	285
10 MID	Box	27.758	268
10 BOT		30.016	283
11 TOP	Bung	29.195	277
11 MID		29.282	278
11 BOT		30.103	283
19 TOP		29.893	281
19 MID	Bung	29.779	280
19 BOT		24.748	252
20 TOP		30.952	288
20 MID	Box	30.429	285
20 BOT		30.174	283

Heat: Mean Rc = 29.245 BHN = 278

Billet Mean:

1 = 30.852	11 = 29.526
2 = 27.002	19 = 28.140
10 = 29.429	20 = 30.518

Method Mean:

Box = 30.298
Bung = 28.223

Location Mean:

	Box	Bung	Both
TOP	31.451	29.963	30.707
MID	29.517	28.343	28.931
BOT	29.830	26.360	28.095

The overall hardness of the Republic Steel is Rc 34.35, more than Rc 5, higher than the Bethlehem overall of Rc 29.245. Republic's HF-1 is slightly harder on the bottom of all billets.

The mean hardness for Bethlehem's Box Cooled material is Rc 30.298 and that for Bung Furnace Cooled is Rc 28.223.

The box cooled material is slightly more consistent in hardness from top to bottom within a billet with the highest consisting in Billets 20T, C and X.

Elevated Temperature Tests (Burning Tests)

In order to determine the effect of elevated temperatures on the structure of as-received HF-1 steel, samples were heated to 1120°C (2050°F), 1148°C (2100°F), and 1205°C (2200°F), air cooled, polished, and deeply etched with Wesley-Austin Solution (see Appendix K). Under close examination, no melting was encountered at the triple points of austenite grain boundaries, as illustrated in figures 2 thru 4.

A sample was heated to 2400°F, air cooled, polished, and deeply etched as before. This sample clearly shows the effect of inter-granular melting (figure 5). It was noticed that if a sample was not overheated the grain boundaries were white on initial etching while in an over heated sample the grain boundaries immediately turned black and polishing delineates the grain boundaries.

Figure 2. Photomicrograph of Austenitic grain triple point after heating to 1120°C (2050°F).

Figure 3. Photomicrograph of Austenitic grain triple point after heating to 1148°C (2100°F)

Figure 4. Photomicrograph of austenitic grain triple point after heating to 1205°C (2200°F)

HF-1

Burning - Experimental

A.

B.

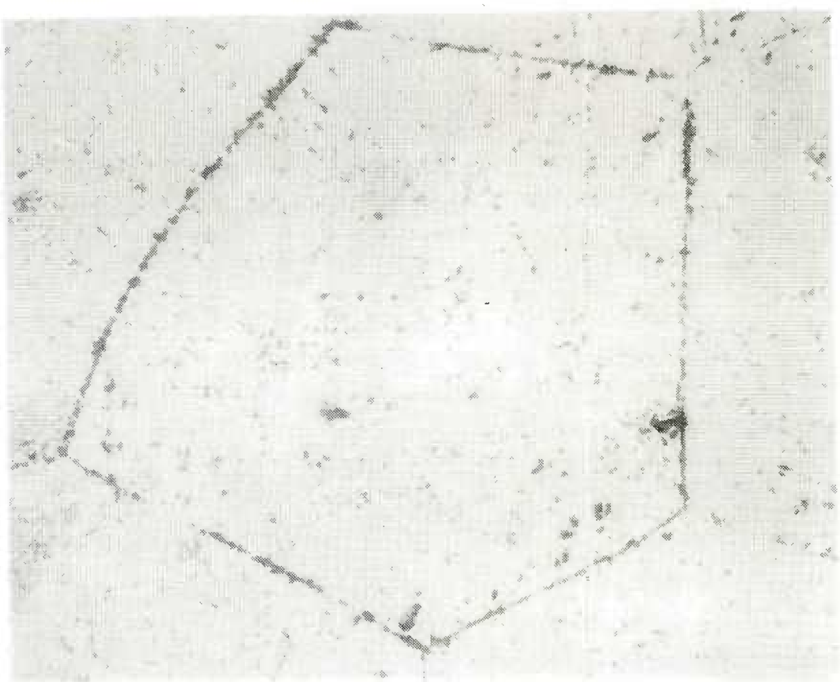


Figure 5. Photomicrograms of Austenitic Grain triple point after heating to 2400°F

a. 63 x etched and polished
b. 125 x etched and polished

Metallography - as received

Republic Steel Corporation

Each billet was sectioned metallographically. All billets showed a fine pearlite rim varying from 0.025 to 0.055, progressing towards a fine to coarse pealitic core. These structures are illustrated in figures G1 thru G9. Figure 5 is a magnified composite of the bottom billet of the twentieth ingot.

The rim is four points harder on the Rockwell C scale than the core. This is not a significant variation in a hot forging operation since the structure would be homogenized at forging temperature.

Bethlehem Steel Corporation

Each billet was sectioned and examined. The billets from the ingots that were box cooled (ingots 1, 10, and 20) revealed the same rim-core structure as billets from Republic Steel. Some of the billets that were bung furnace cooled had a broken-up pearlitic structure. This can be expected as the bung furnace produces a slower, more controlled cooling.

These structures are illustrated in figures G10 thru G27. Figures 6 and 7 illustrate the magnified composite of a bung and furnance cooled structure of an ingot.

Inclusions

Republic Steel

On first analysis, optical microscopy was unable to reveal the exact nature of some of the inclusions. All samples exhibited a grey elongated type of inclusion. This is typical of Manganese sulfide; but in this instance black areas were associated with the grey inclusions.

A good example of this is illustrated by figures 8 and 9. In order to ascertain the exact nature of the inclusion, it was examined by a Scanning Electron Microscope (SEM) with an Electron Defraction X-ray Analyzer attachement (EDAX). Analysis of the grey mass proved that it was a Manganese sulfide as illustrated in figure 10. The black area was then analyzed and revealed the following elements: Aluminum, Silicon, Sulfur, Calcium, Manganese, Titanium and Iron. This is illustrated in figure 11.

Figure 12 is an anlysis of the area away from the inclusion showing only manganese and iron.

Bethlehem Steel

Inclusions from Bethlehem Steel are illustrated in figure 13 and were evaluated in the same manner as those from Republic Steel. The grey areas in figure 13 were analyzed and showed Manganese Sulfide again as shown in figure 14.

The black areas associated with the grey inclusions were analyzed and revealed the following elements: Aluminum, Calcium Sulfur, Manganese and Iron. Notice in Bethlehem's material that there is no Titanium or Silicon. This is illustrated in figure 15. The stringer inclusions are silicates.

An old inclusion was detected in this material. It was square and angular with a black spot in it as illustrated in figure 16. An EDAX evaluation (figure 17) of the grey square revealed the following elements: Aluminum Silicon, Calcium Titanium and Iron. The base compound has been identified as Titanium Nitrite. The black spot (figure 18) contains only Titanium and Iron. Figure 19 is an EDAX evaluation of background. The analyses of both heats contained variations in the levels of the individual elements of their contents.

All inclusions were rated according to the ASTM E-45 standard method. Some difficulty was experienced during the final polishing of the specimen. Normal practice of polishing suggests an aqueous suspension of Alumina. This practice smeared the sulfide inclusions and sometimes spotted the specimen. It was found that an alcohol suspension of Alumina must be used to produce clearly defined inclusions.

The inclusion ratings are as follows:

Micro-Cleanliness (Inclusion Rating)

The micro-cleanliness of the two heats of steel was rated according to ASTM E45-76 method D, as previously stated these two major inclusions present, sulfide and silicates.

TABLE 13. Inclusion Rating - Republic

	Manganese Sulfide	Calcium Silicate
1AA	A 1½ thin	C 2-2½ heavy
1BA	A 2 thin	C 1 thin
1BD	A 2½ thin	C 1 thin
20AA	A 1½ thin	C 1 thin
20BA	A 1½ thin	C 1 thin
20BD	A 1½ thin	C ½ thin
40AA	A 1½ thin	C 1½ heavy
40BA	A 1½-2 thin	C 2 heavy
40BD	A 1½ thin	C 1 thin

TABLE 14. Inclusion Rating - Bethlehem

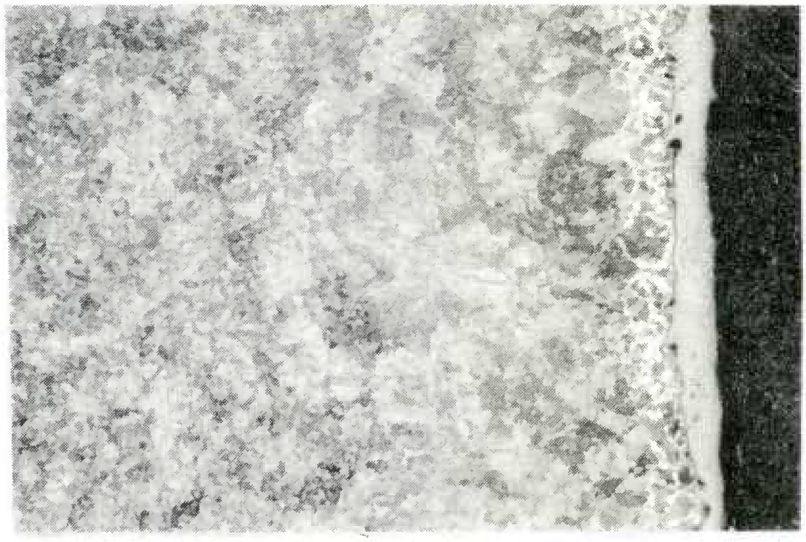
	Manganese Sulfide	Calcium Silicates
1T	A 2 thin	C 2½ heavy
1C	A 1 thin	C 1½ thin
1X	A 2 thin	C 2 thin
2T	A 1½ thin	C 2 thin
2C	A 1½ thin	C 1 thin
2X	A 1½ thin	C 1 thin
10T	A 2 thin	C 1½ thin
10C	A 1½ thin	C 1 thin
10X	A 1 thin	C 2 thin
11T	A 2 thin	C 1 thin
11C	A 2 thin	C 1 thin
11X	A 2 thin	C 2 thin
19T	A 2½ thin	C 1½ heavy
19C	A 1½ thin	C 1 thin
19X	A 2 thin	C 1½ thin
20T	A 2 heavy	C 2 thin
20C	A 2 thin	C 2-2½ thin
20X	A 2 thin	C 1½ thin

From the inclusion rating tables, it can be seen that Republic Steel is somewhat cleaner than the heat from Bethlehem Steel. This was expected and is due to Electric furnaces versus Basic Oxygen furnaces practices.

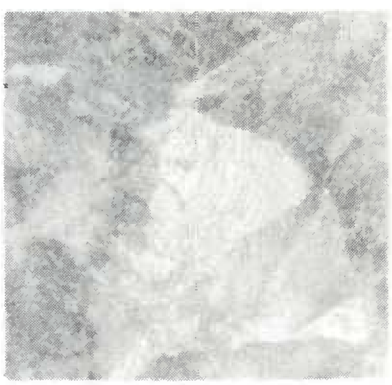
Figure 20 is an example of a typical inclusion of Republic Steel.

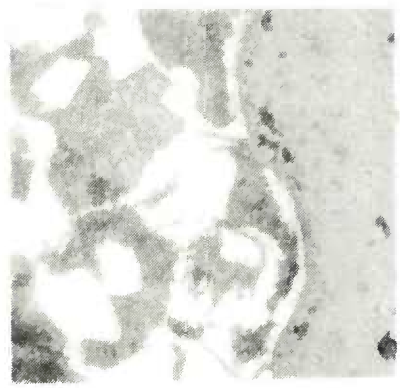
Figure 21 is an example of a typical inclusion of Bethlehem Steel.

Republic Steel Billet 20BD



63x Cross Section



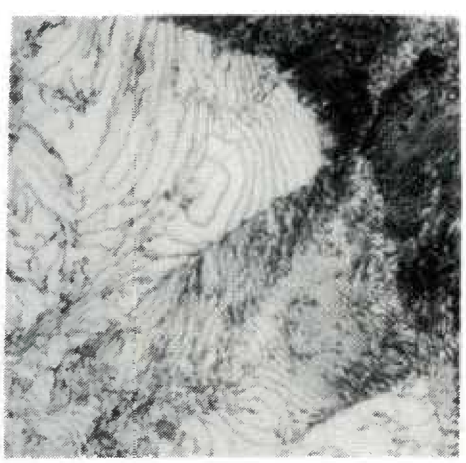


500x Cross Section

Core

Rim
width 0.051 inches

Edge
Scale 0.004 inches



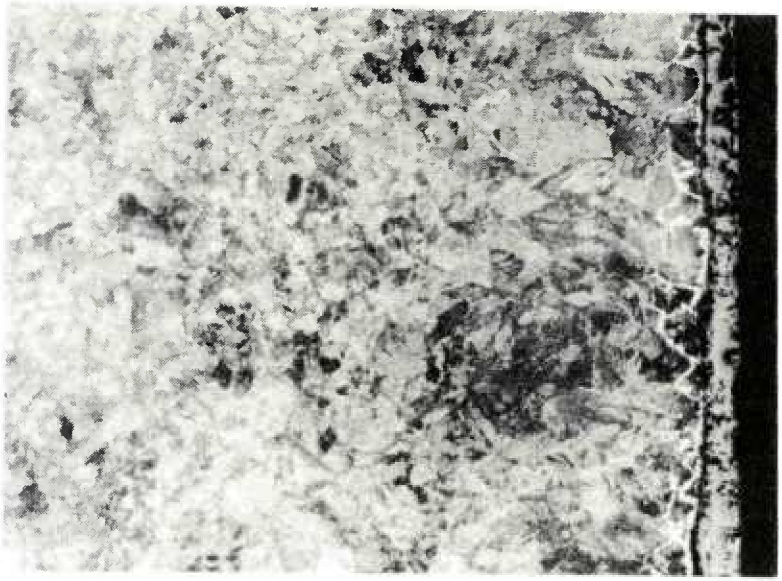
1000x Cross Section

Core

Rim

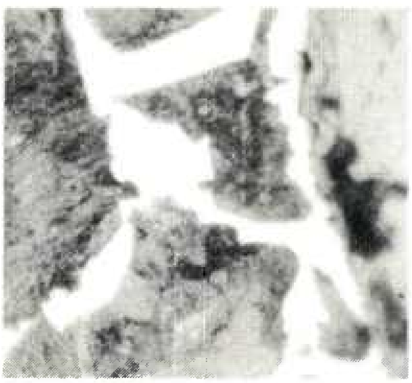
Figure 6. Composite Structure. Picral Etchant.

Bethlehem Steel
20C



63x Cross
Sectio





500x
Cross
Sect

Core

Rim
width .025 inches

Ecge
Scale 0.004 inches

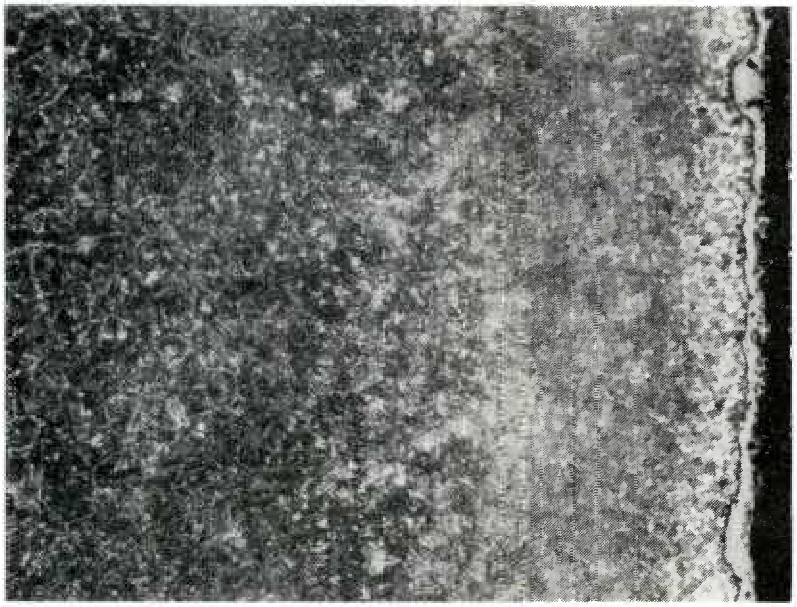

1000x
Cross Secti

Core

Rim

Figure 7. Composite Structure. Picral Etchant

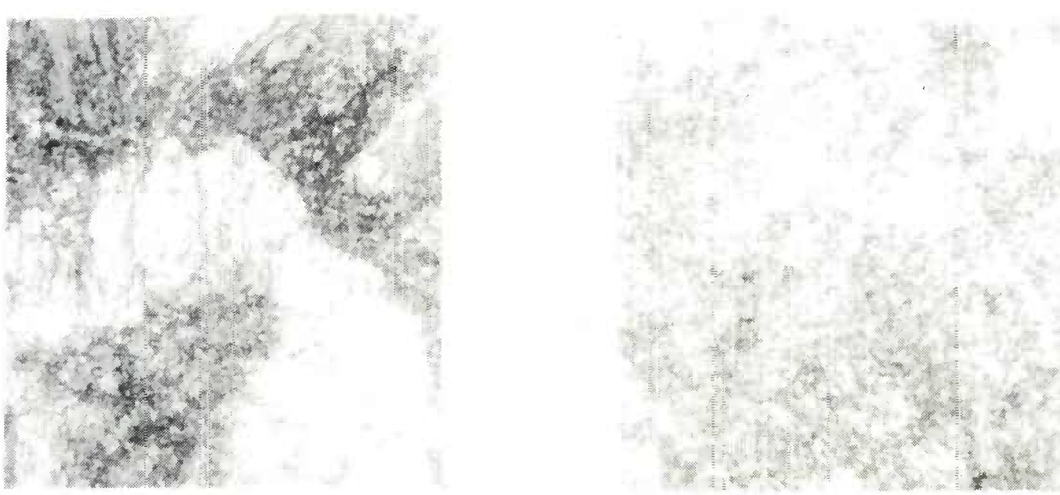
Bethlehem Steel
2T



63x Cross Section

500x Cross Section

Core | Rim width 0.024 inches | Edge Scale 0.001 inches



1000x Cross Section

Core | Rim

Figure 8. Composite Structure. Picral Etchant.

REPUBLIC STEEL

SEM

Inclusion Analysis

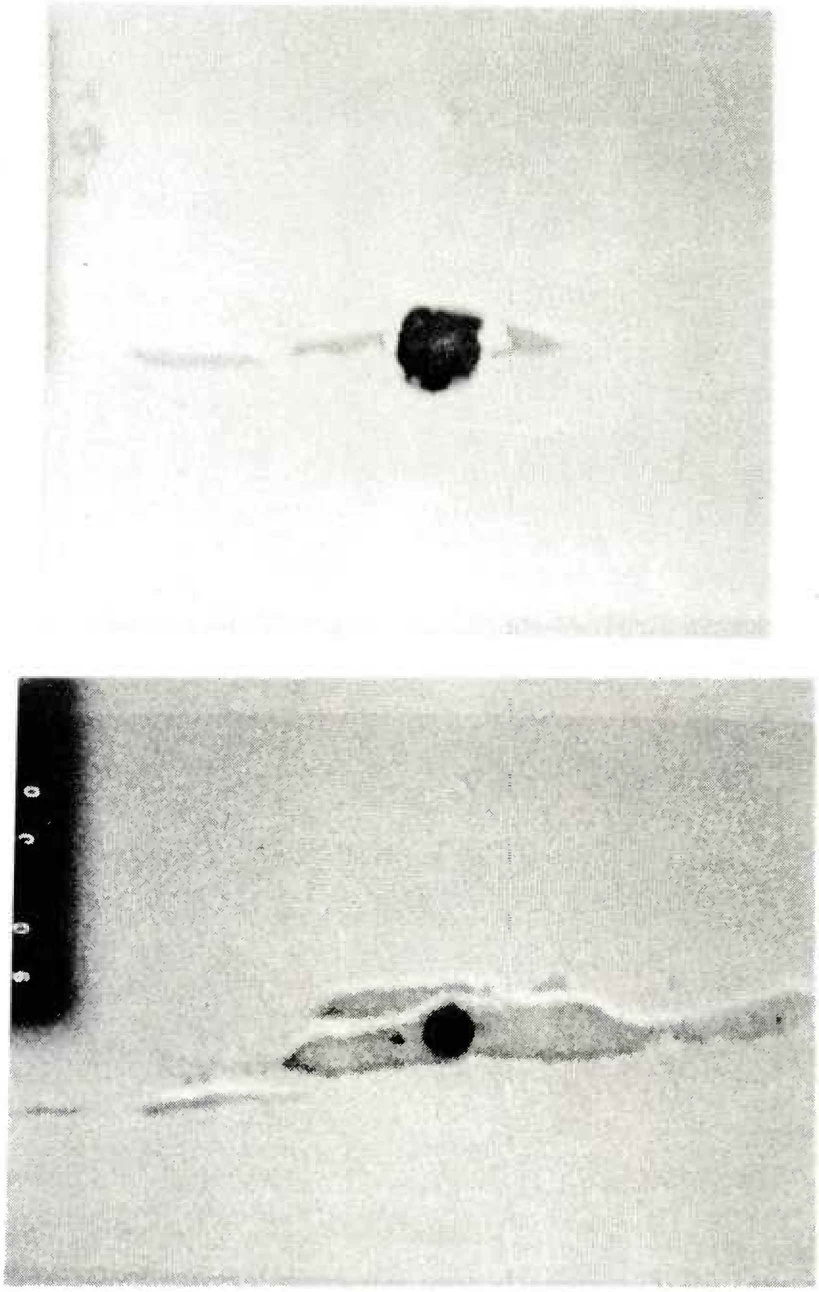
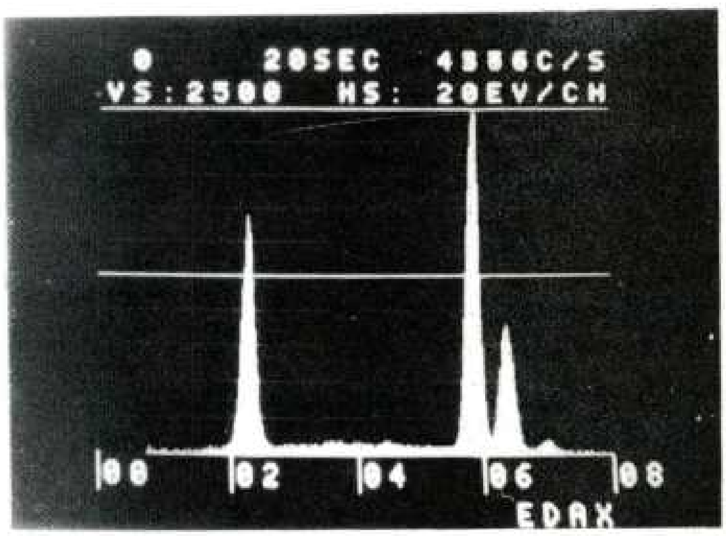


Figure 9. Two illustrations of inclusion from Republic 20BD. 1000x

REPUBLIC STEEL

SEM

EDAX Evaluation of Inclusion



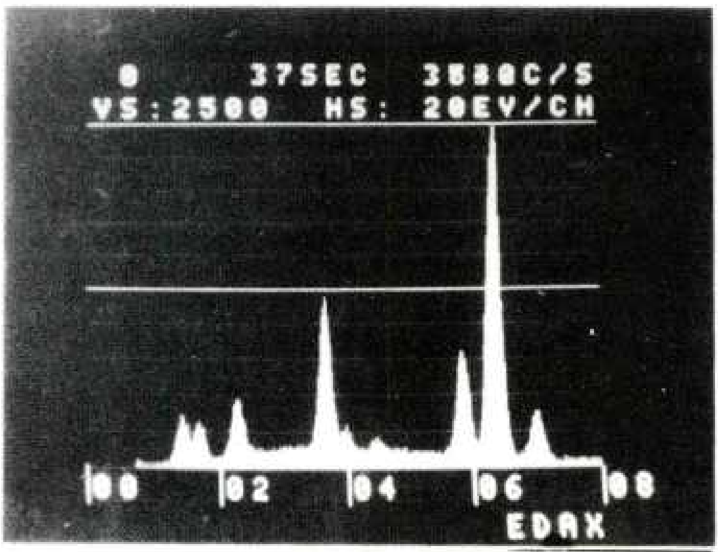
S Mn Fe Fe

Figure 10. EDAX Evaluation of grey area of inclusion indicating Manganese sulfide.

REPUBLIC STEEL

SEM

EDAX Evaluation of Inclusion



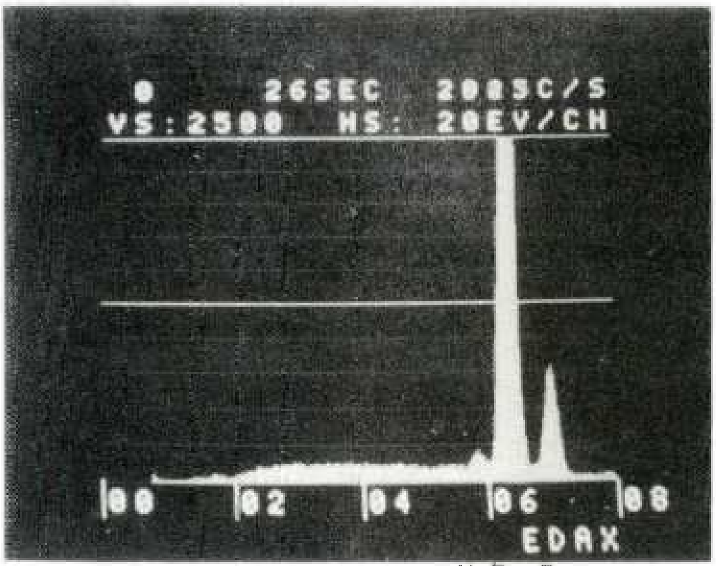
AlSi S Ca Ti MnFe Fe

Figure 11. EDAX Evaluation of black area of inclusion indicating a complex calcium silicate.

REPUBLIC STEEL

SEM

EDAX Analysis of Inclusion



MnFe Fe

Figure 12. EDAX Evaluation of area away from inclusion. (background)

BETHLEHEM STEEL

SEM

Inclusion Analysis

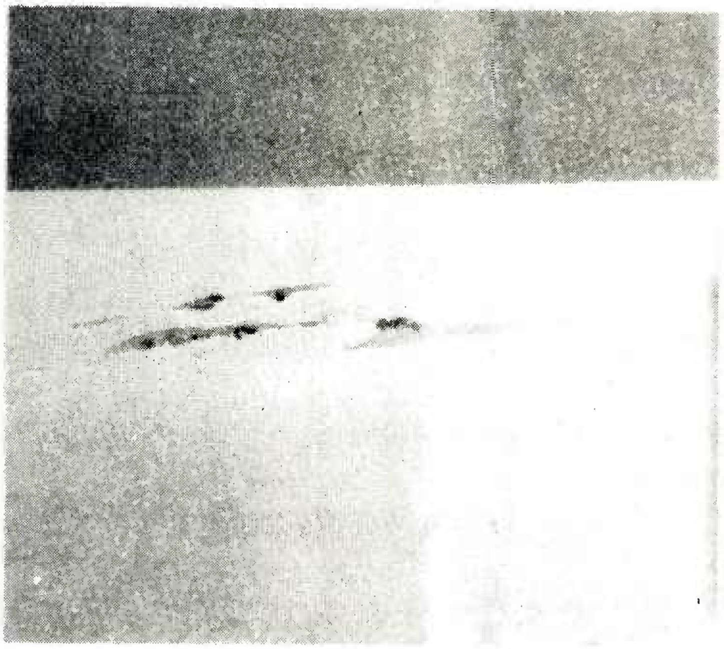
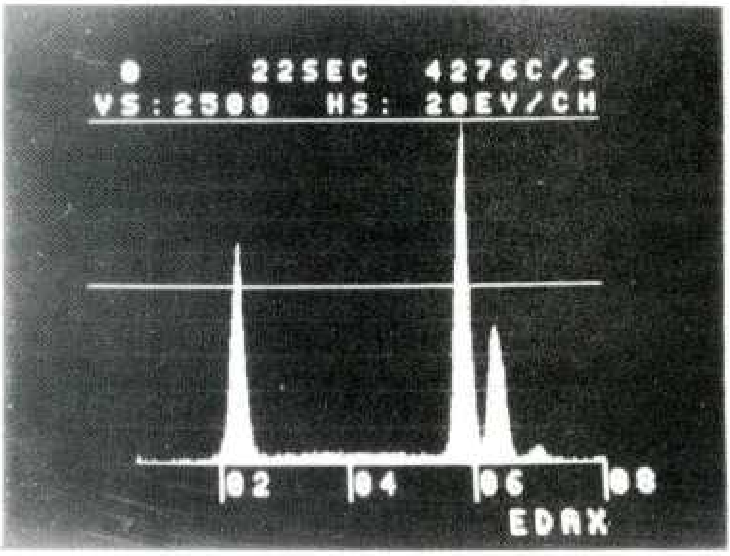


Figure 13. Illustration of stringer inclusion with black area. 500x

BETHLEHEM STEEL

SEM

EDAX Evaluation of Inclusion



S Mn Fe Fe

Figure 14. EDAX Evaluation of grey area indicating manganese sulfide.

BETHLEHEM STEEL

SEM

EDAX Evaluation of Inclusion

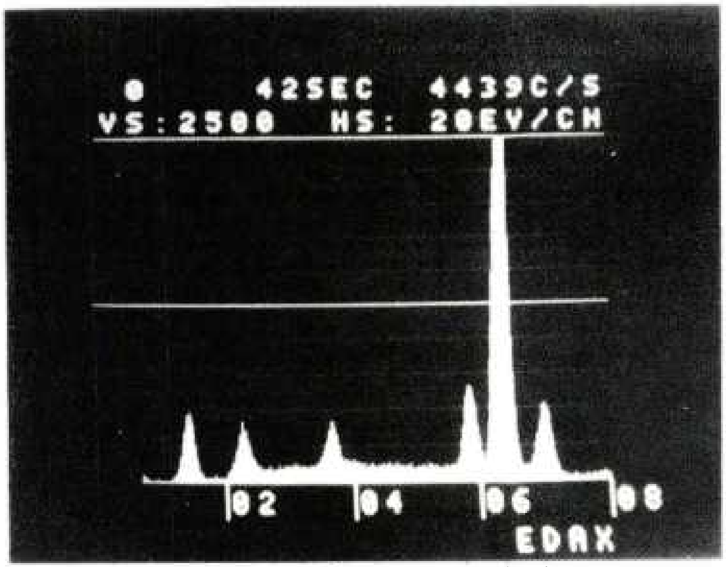
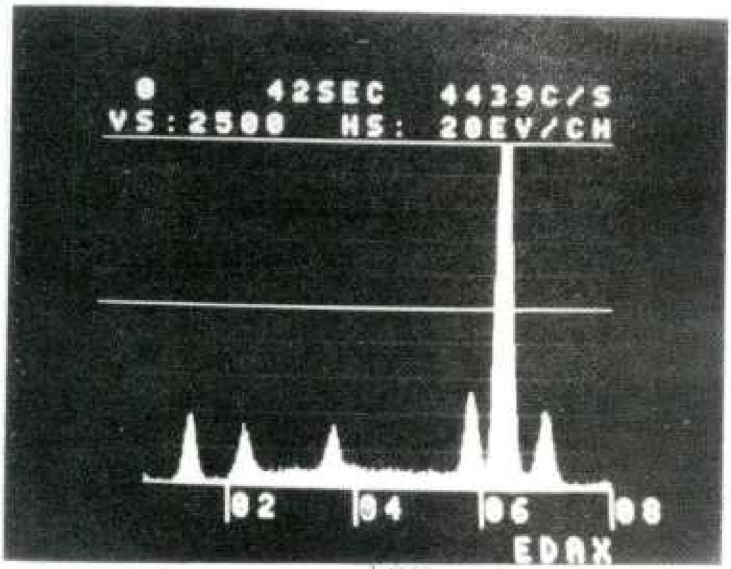


Figure 15. EDAX Evaluation of grey area in figure revealing a complex sulfide.

BETHLEHEM STEEL

SEM

EDAX Evaluation of Inclusion



Al S Ca Mn Fe Fe

Figure 16. EDAX Evaluation of black area indicating a complex calcium alumina sulfide.

BETHLEHEM STEEL

SEM

EDAX Evaluation of Inclusion

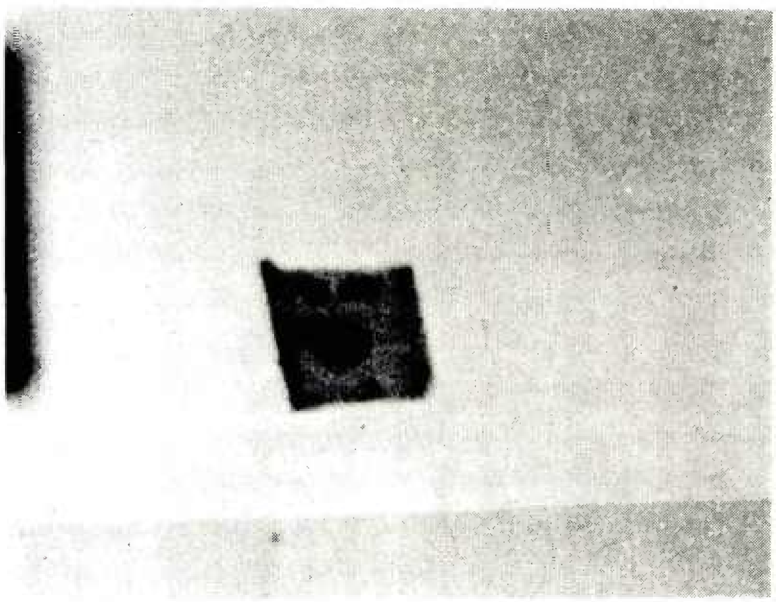
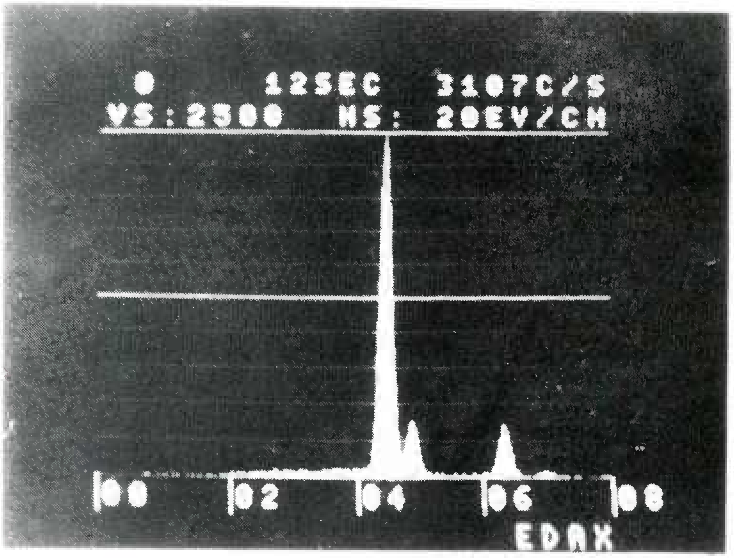


Figure 17. Illustration of odd inclusion. 2000x

BETHLEHEM STEEL

SEM

EDAX Evaluation of Inclusion



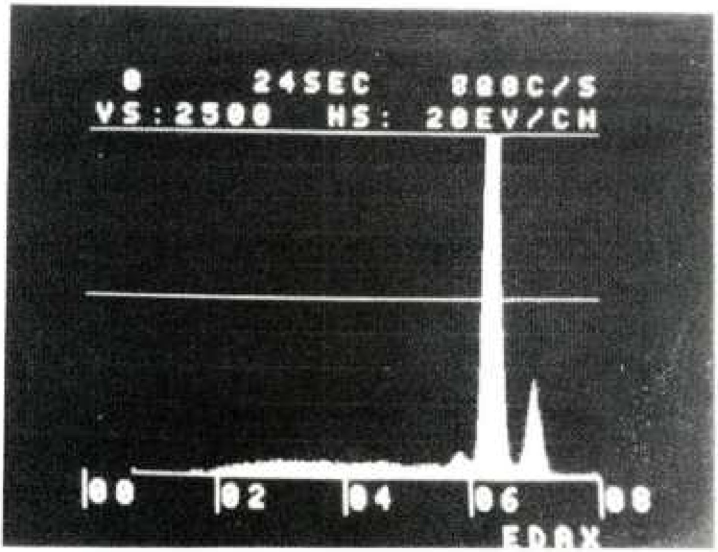
Ti Ti Fe Fe

Figure 18. EDAX evaluation of black area in center of square inclusion revealing high purity titanium and iron.

BETHLEHEM STEEL

SEM

EDAX Evaluation of Inclusion

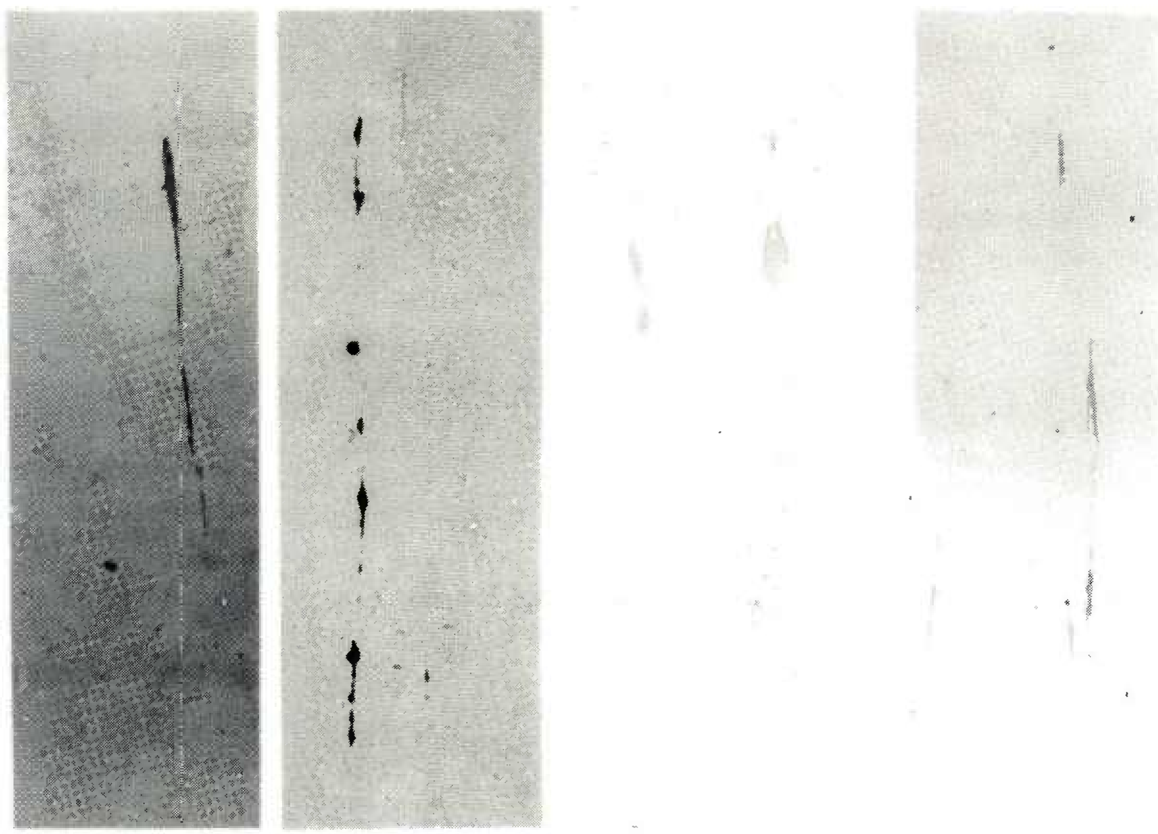


Mn Fe Fe

Figure 19. EDAX Evaluation of area away from inclusion.

Republic Steel

Inclusions

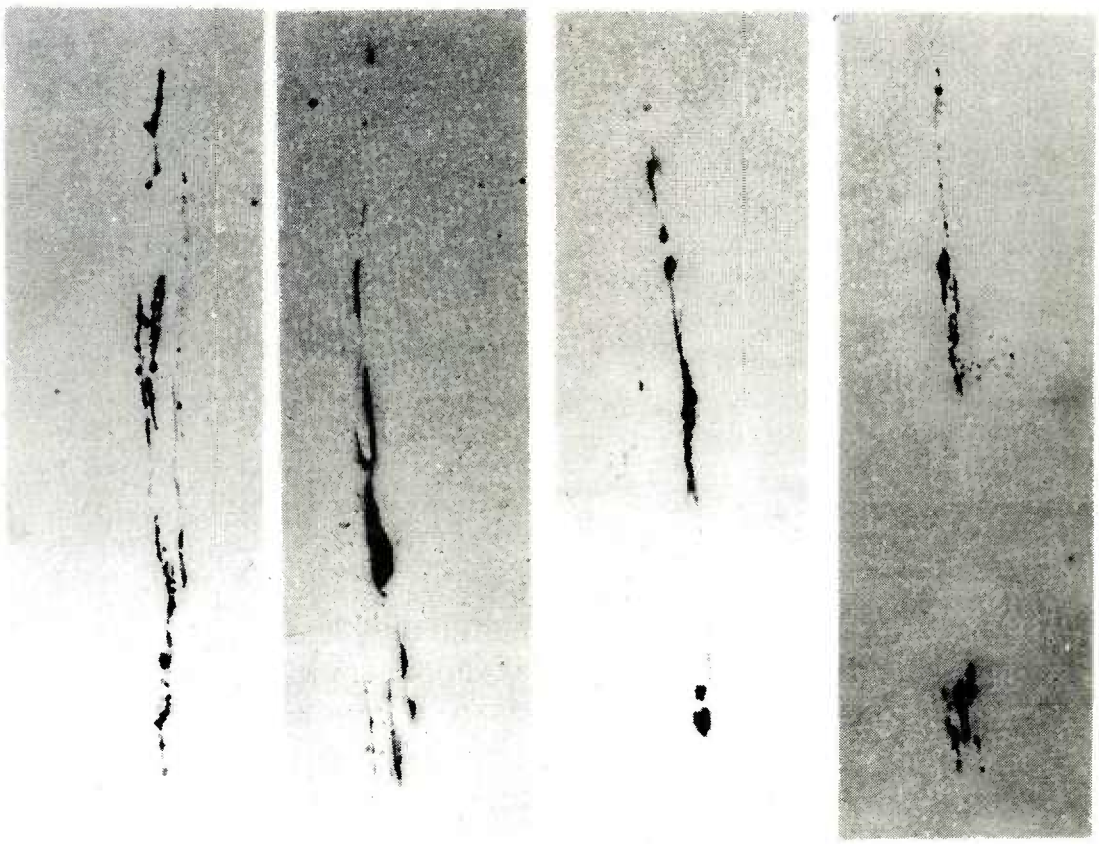


40AA 40BA 20BA 20BD

Figure 20. Typical Inclusions. 125x.

Bethlehem Steel

Inclusions



1X 1C 2T 10X

Figure 21. Typical Inclusions. 125x.

Heat Treatment

Scope of Work MFX-001 requires HF-1 steel to meet a yield strength of 827 MPa (120,000 PSI) and an elongation of 12%. In order to determine the temperature for Austenitization and tempering to attain these properties, the Isothermal Transformation diagram (fig. 22) was first consulted. Austenitization temperatures deemed acceptable for testing were 843°C (1550°F), 815°C (1500°F) and 804°C (1480°F). Soaking time was set at one hour.

Before tempering tests were begun, samples austenitized at the above temperatures were metallographically evaluated to determine the effect of these temperatures on the size of the martensite as-quenched platelets and the amount of retained austenite. Figures 23 thru 26 show the variation and figure 27 illustrates fine spots that appear when water is used for polishing and rinsing. All other samples were polished with an alcohol suspension of aluminum and subsequently rinsed in alcohol (anhydrous).

Tests 1 through 8 described below, were conducted on Billet 1AA of Republic Steel.

Test 1

Austenitized at 843°C (1550°F), for 1 hour.

Eight 1 inch diameter longitudinal coupons were austenitized at 843°C (1550°F). Of these, two were tempered at 593°C (1100°F), two at 638°C (1180°F), two at 677°C (1250°F) and two at 760°C (1400°F). Tempering time was one hour for all, followed by quenching in TexQuench 500 (Tex-Quench A) oil at 27°C (80°F). Tensile bars for these tests were standard specimens, machined to 0.505 inch. The mechanical properties attained at various tempering temperatures were extremely low and are plotted in figure 28.

Upon metallographic evaluation, small white areas were discovered in a coupon from this group which could be ferrite particles caused by slack quench, or small carbide due to insufficient austenitizing time (fig. 29).

Test 2

These white areas and the low mechanical properties led to the next stage of testing in which austenitizing time was increased to two hours to investigate the effects of time at temperature on the mechanical properties. The temperature (843°C/1550°F) used in the first series of tests was maintained for this series with a tempering temperature of 638°C (1180°F). No significant changes occurred in either mechanical properties or microstructure.

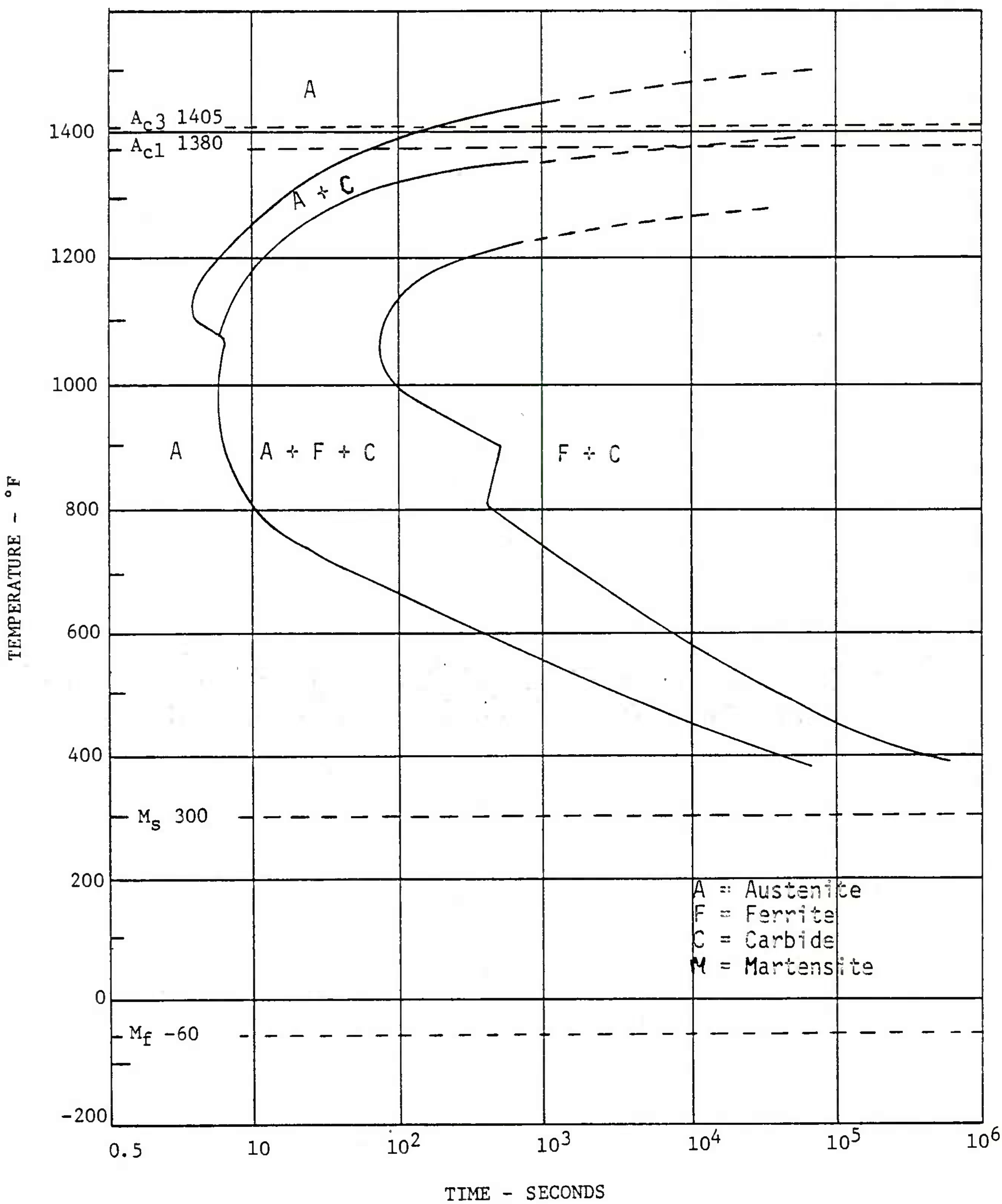


Figure 22. ISOTHERMAL TRANSFORMATION DIAGRAM FOR HFI STEEL

Test 3

Again maintaining the 843°C (1550°F) austenitizing temperature and a one inch coupon, the next parameter to be examined was the quenchant. Texaco Oil Company specifies the fastest quench attainable with TexQuench A is 12.5 seconds at approximately 65°C (150°F) according to the G.M. Quenchometer Test. After a one hour soak, the coupon was quenched in TexQuench A at 65°C (150°F) and tempered at 638°C (1180°F).

There was no significant change in yield strength. Elongation increased from 12.5% to 14.5%. The microstructure (figure 30) revealed the same white areas observed in the initial series, in an untempered, martensite matrix. Rockwell C hardness was 63-64.

Figure 23. Photomicrograph of untempered martensite with some retained austenite (white area) in sample austenitized at 843°C (1550°F). 1000x

Figure 24. Photomicrograph of untempered martensite with less retained austenite (white area) this figure. This sample was austenitized at 829°C (1525°F). 1000x

Test 4

The next series was performed with coupons of 3/4 inch section thickness to improve the effect of quenching in oil. Initial results provided a yield strength of 800 MPa (116 ksi) and a 16% elongation, an improvement from previous tests. There was a marked decrease in the amount of white areas in the microstructure of the as-quenched samples. These white areas were not continuous, as were those in previous samples, leading to the conclusion that they are ferrite, produced by insufficient quench speed. These areas were later proved to be carbides.

Test 5

This series of tests held constant the 3/4" diameter coupon size, austenitizing temperature of 843°C (1550°F) and quench temperature 65°±5.5°C (150°F±10F). Tempering temperatures were varied with acceptable results obtained at a tempering temperature between 593°C (1100°F) and 616°C (1140°F). For a plot of these results see figure 31. Because this temperature range is entirely too narrow to be reasonably maintained during production, the next series was run as an attempt to widen the range.

Test 6

Constants in this series were: austenitizing temperature of 804°C (1480°F) for one hour; quench in TexQuench A at 65°C (150°F). Again, tempering temperatures were varied. Acceptable results were achieved in the tempering range of 580°C (1075°F) to 640°C (2285°F) with yield strengths of 920 MPa (133 ksi) and 827 MPa (120 ksi). The elongations plotted for these yields were 13% and 15% respectively, (see figure 32). Coupons heat treated in this series of tests revealed a very fine, untempered martensite (figure 26) with a Rockwell C hardness of 61-62.

Test 7

In this series 3/4 inch diameter coupons were austenitized for one hour at 815°C (1500°F) and quenched in Tex Quench A at 65°C (150°F). Tempering temperatures were again varied and the results plotted in figure 33. All curves exhibit a sharp increase in yield strength and decrease in elongation at 753°C (1380°F), which is the lower critical (Ac) for HF-1. At this temperature, the coupons become partially reaustenitized.

Before further testing was undertaken, discussions were held at ARRADCOM during which it was determined to austenitize all further series at 915°C (1500°F) and to quench at 65°C (150°F) in Tex-Quench A.

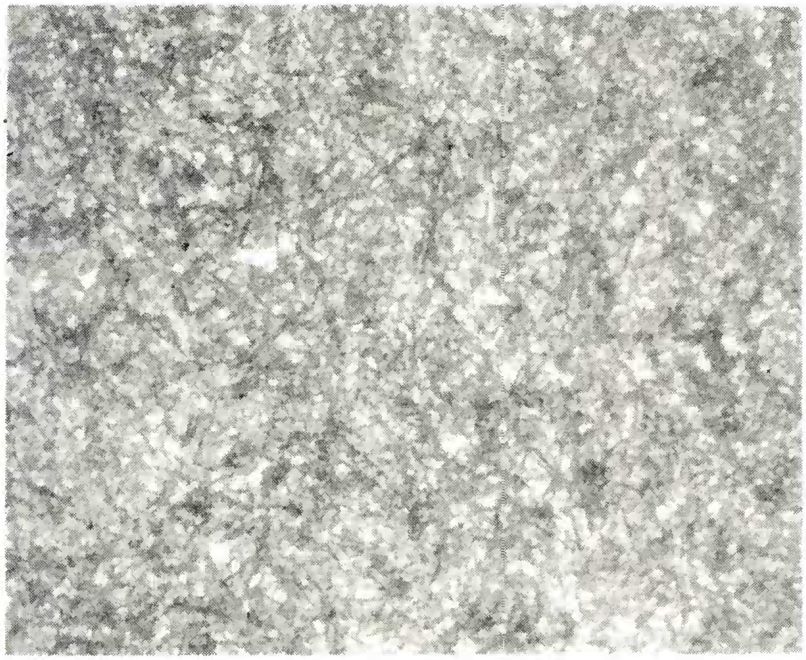


Figure 25. Photomicrograph of untempered martensite with very little amounts of retained austenite. This sample was austenitized at 815°C (1500°F). 1000x

Figure 26. Photomicrograph of untempered martensite with very little amounts of retained austenite. This sample was austenitized at 804°C (1480°F). 1000x

HF-1
As-Quenched Structures

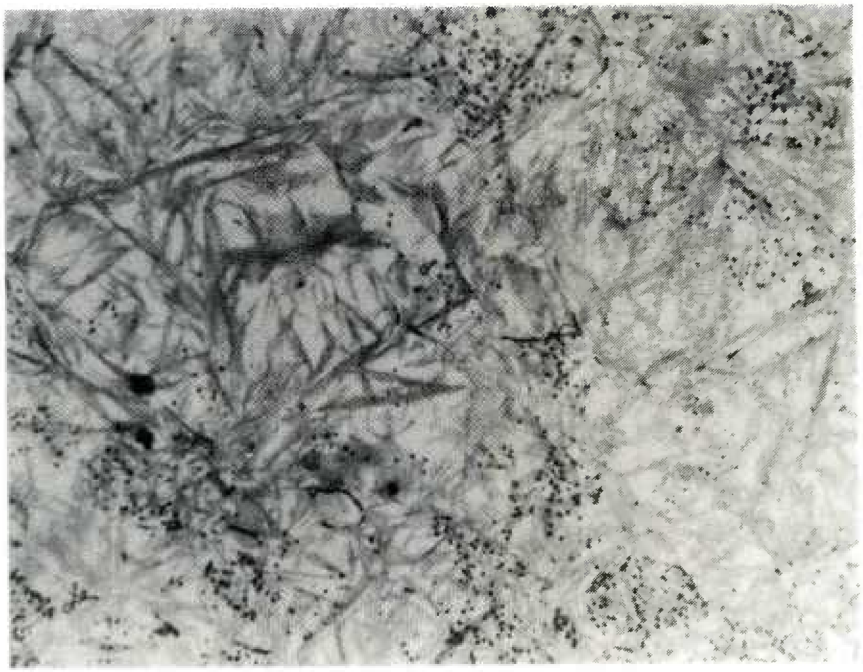
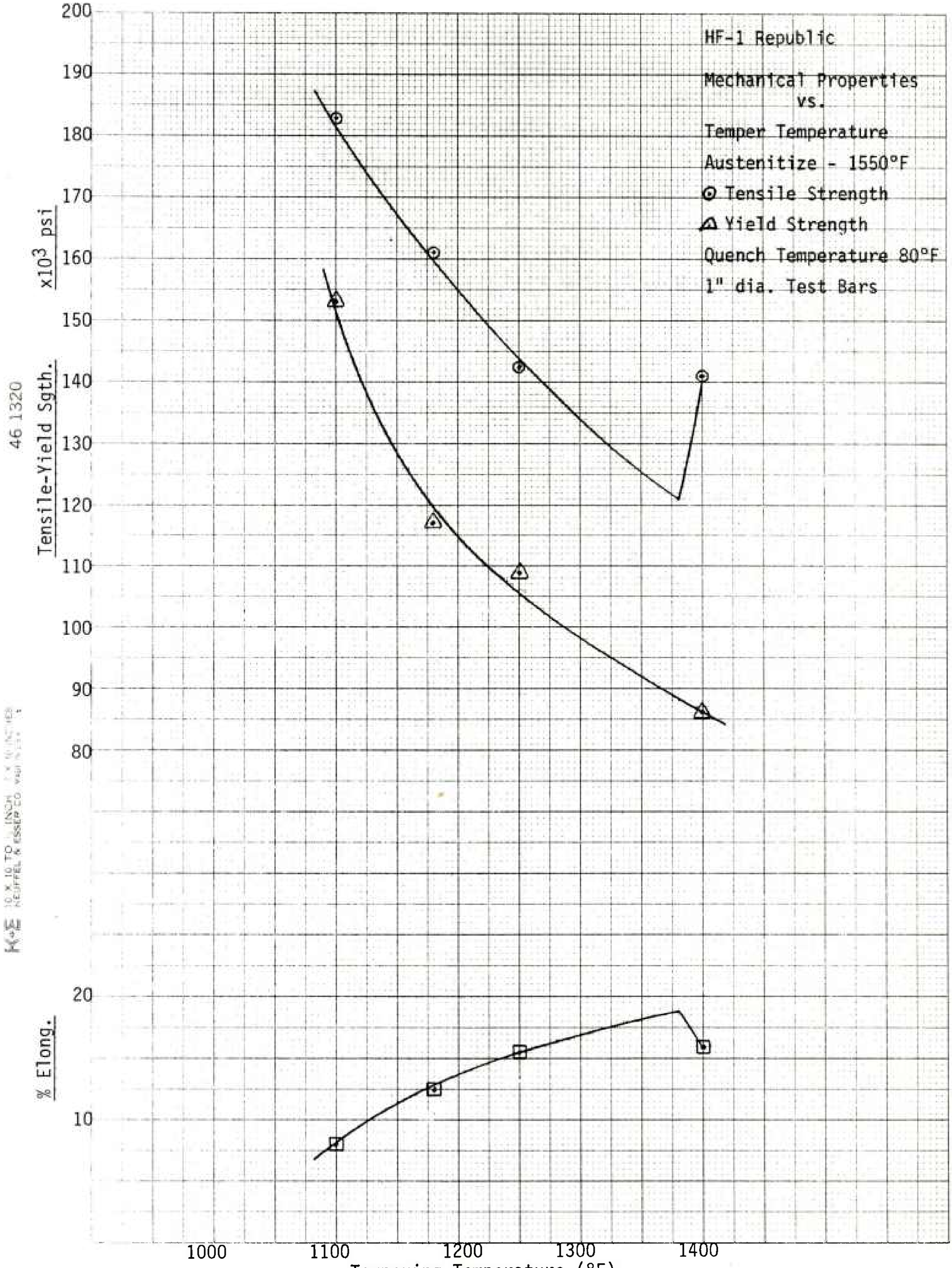


Figure 27. Photomicrograph of untempered martensite with black spot contamination from water polishing and rinsing. This sample was austenitized at 843°C (1550°F). 1000x



HF-1 Republic
Mechanical Properties vs. Temper Temperature
Austenitize - 1550°F
Tensile Strength
Yield Strength
Quench Temperature 80°F
1" dia. Test Bars
Tensile-Yield Sgth. x10^3 psi
200
190
180
170
160
150
140
130
120
110
100
90
80
% Elong.
20
10
1000
1100
1200
1300
1400
Tempering Temperature (°F)
46 1320

Figure 28.

HF-1

Figure 29. Photomicrograph showing white areas. 500x 2% Nital.

HF-1

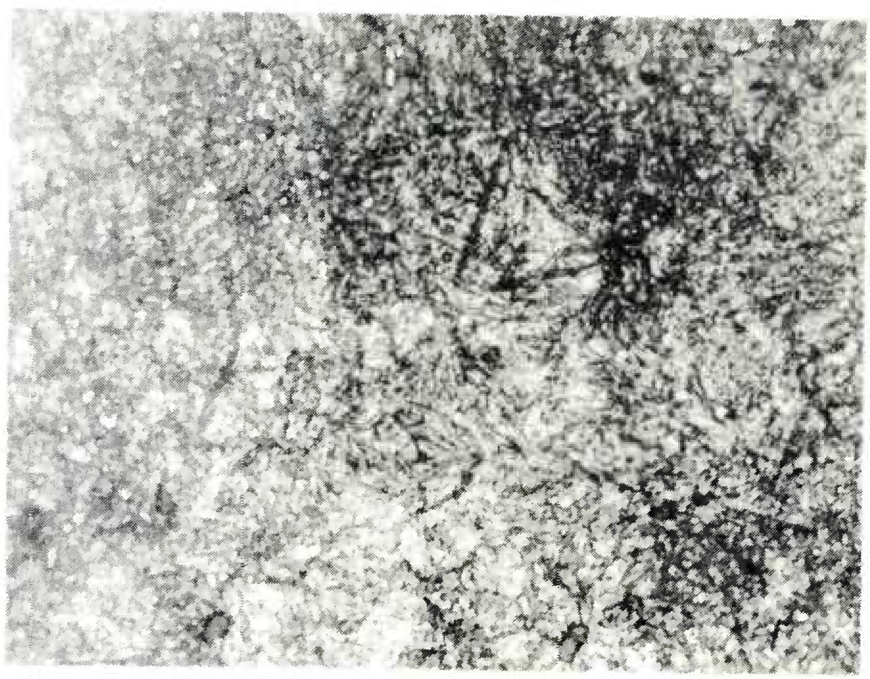
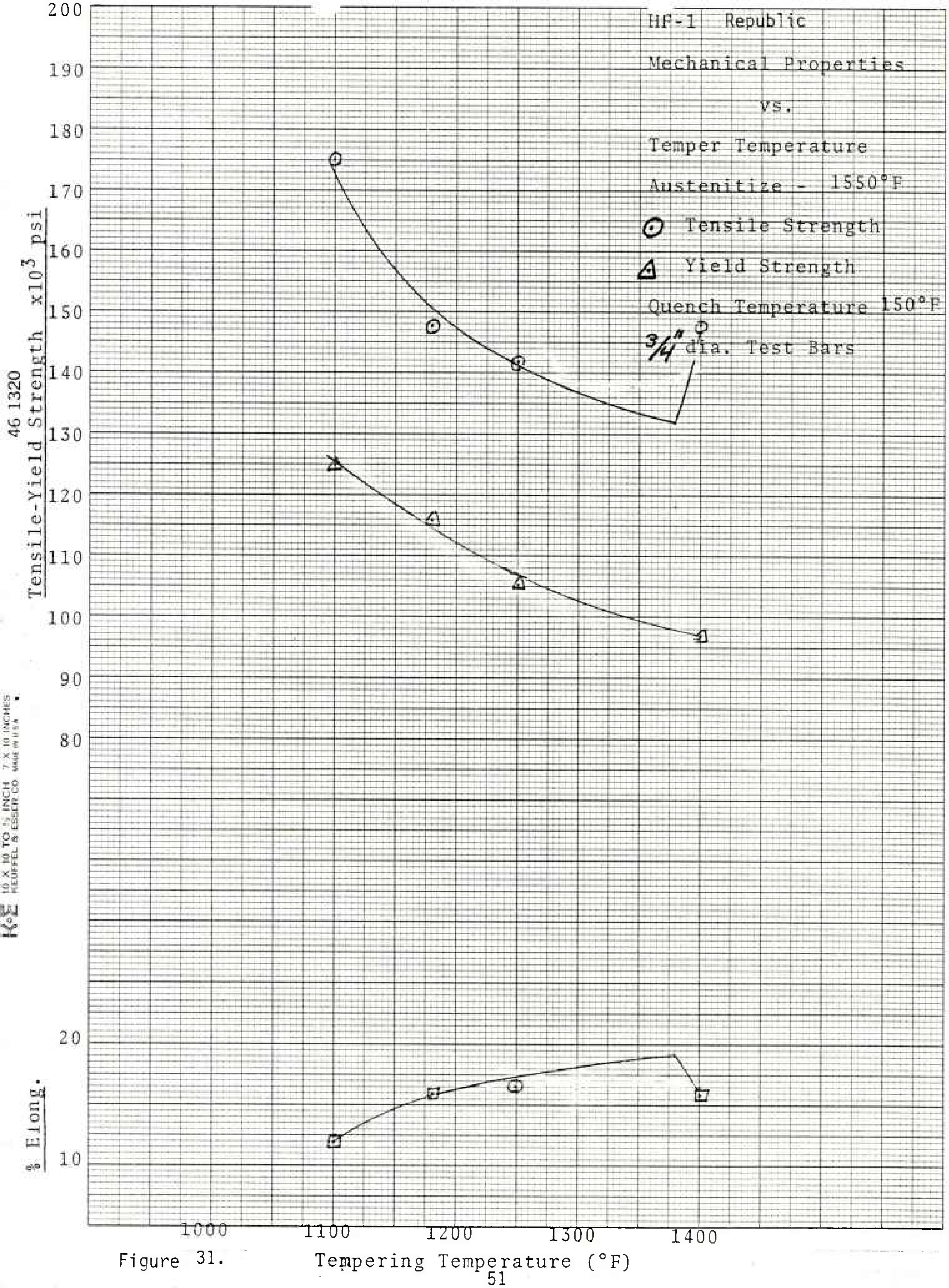


Figure 30. Photomicrograph showing white areas. 1000x 2% Nital.



HF-1 Republic
Mechanical Properties
vs.
Temper Temperature
Austenitize - 1550°F
Tensile Strength
Yield Strength
Quench Temperature 150°F
3/4" dia. Test Bars
Tensile-Yield Strength x10^3 psi
% Elong.
200
190
180
170
160
150
140
130
120
110
100
90
80
20
10
1000
1100
1200
1300
1400
Tempering Temperature (°F)
46 1320
K&E 10 X 10 TO ½ INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.

Figure 31.

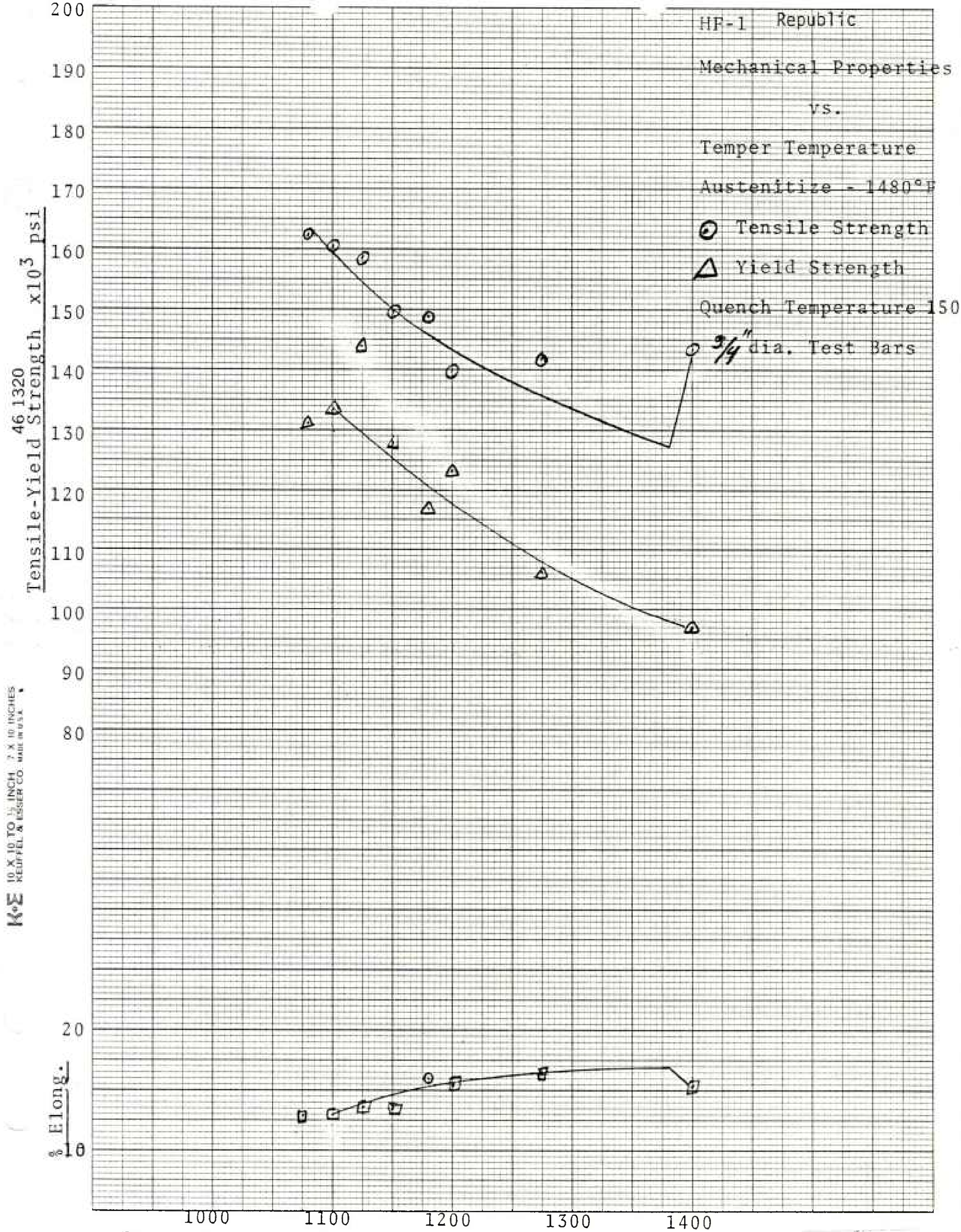


Figure 32. Tempering Temperature (°F)

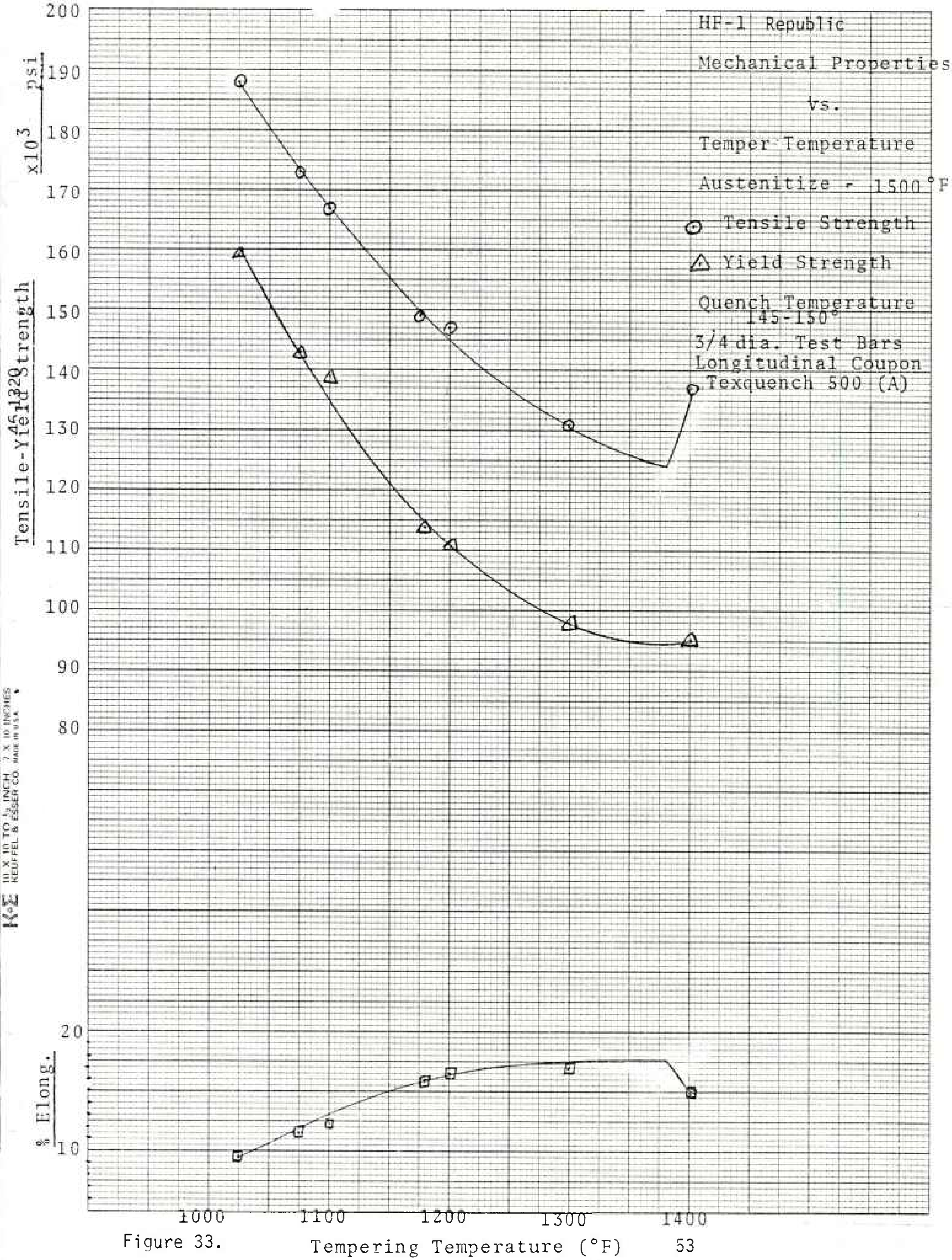

HF-1 Republic
Mechanical Properties
vs.
Temper Temperature
Austenitize - 1500 °F
Tensile Strength
Yield Strength
Quench Temperature
145-150°
3/4 dia. Test Bars
Longitudinal Coupon
Texquench 500 (A)
Tensile-Yield Strength x10³ psi
% Elong.
200
190
180
170
160
150
140
130
120
110
100
90
80
20
10
1000
1100
1200
1300
1400
Tempering Temperature (°F)

Figure 33.

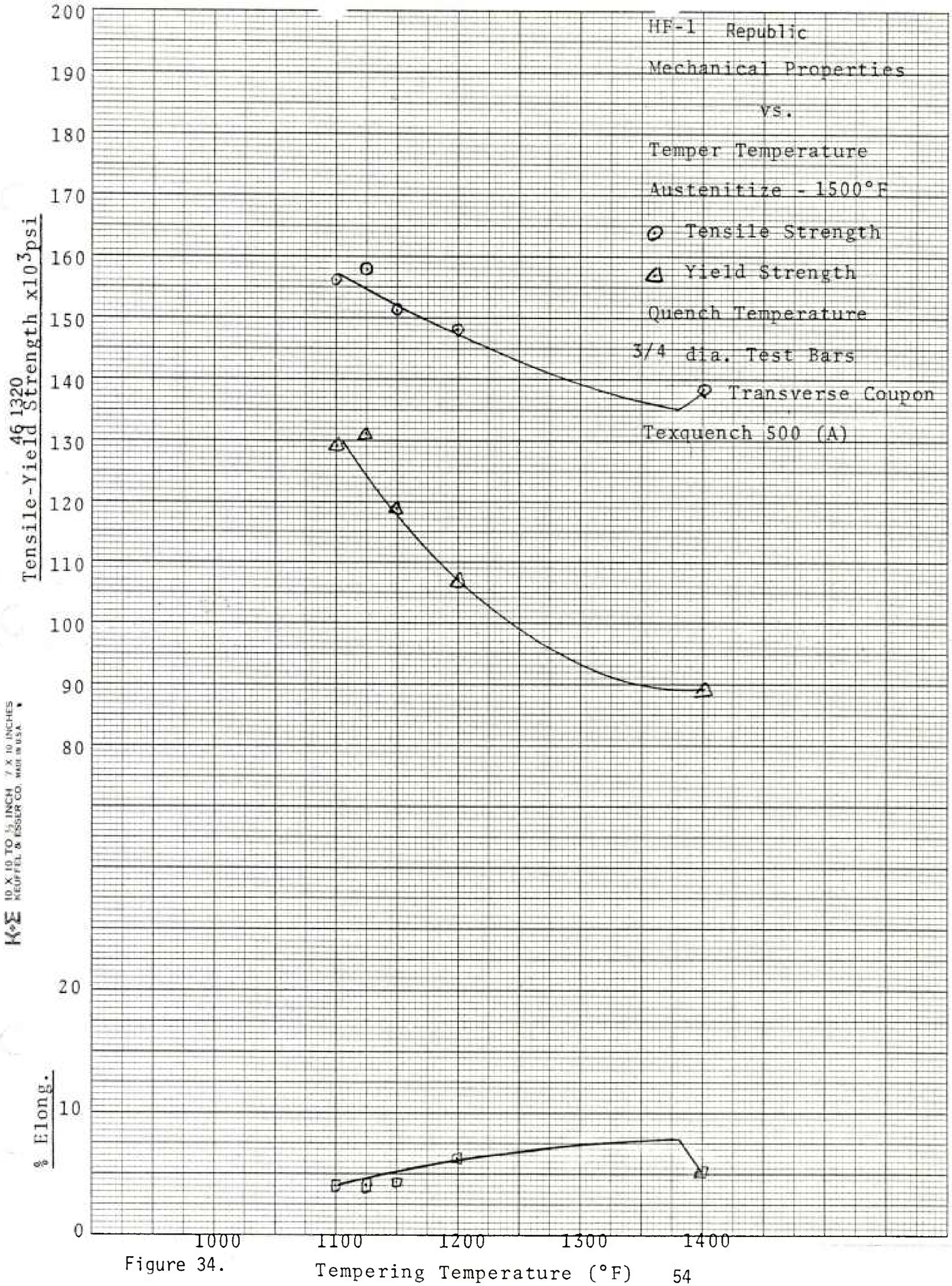

HF-1 Republic
Mechanical Properties
vs.
Temper Temperature
Austenitize - 1500°F
Tensile Strength
Yield Strength
Quench Temperature
3/4 dia. Test Bars
Transverse Coupon
Texquench 500 (A)
Tensile-Yield Strength x10^{3}psi
46 1320
% Elong.
200
190
180
170
160
150
140
130
120
110
100
90
80
20
10
0
1000
1100
1200
1300
1400
Tempering Temperature (°F)
K+E 10 X 10 TO 1/2 INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.

Figure 34.

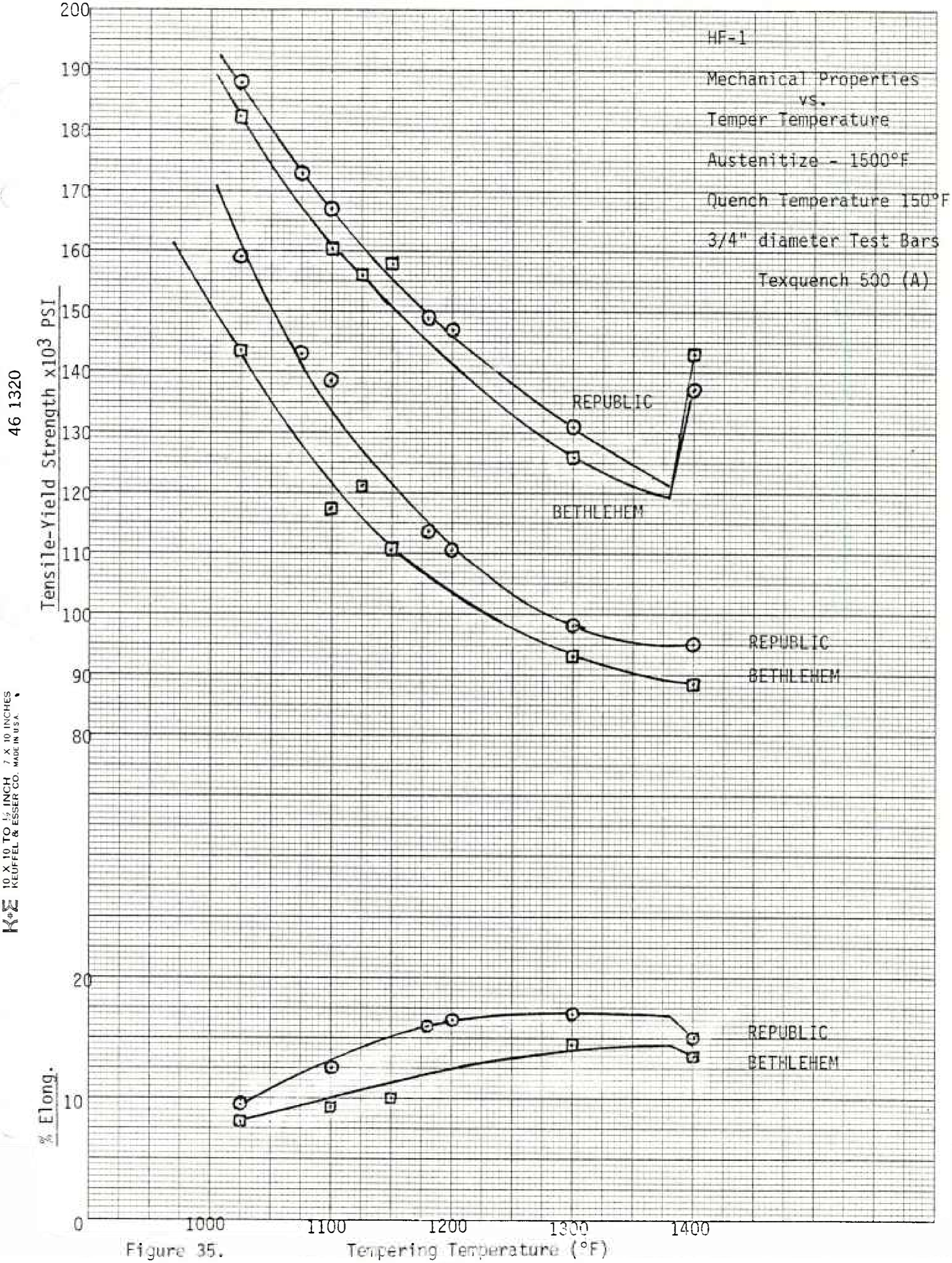

HF-1
Mechanical Properties
vs.
Temper Temperature
Austenitize - 1500°F
Quench Temperature 150°F
3/4" diameter Test Bars
Texquench 500 (A)
REPUBLIC
BETHLEHEM
REPUBLIC
BETHLEHEM
REPUBLIC
BETHLEHEM
Tensile-Yield Strength x10³ PSI
% Elong.
200
190
180
170
160
150
140
130
120
110
100
90
80
20
10
0
1000
1100
1200
1300
1400
Tempering Temperature (°F)
46 1320
K+E 10 X 10 TO ½ INCH 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

Figure 35.

Test 8

The final test on Republic was the heat treatment of transverse samples. The results are plotted in figure 34. Maximum elongation attainable within these parameters is 4.3% at 820 MPa (119 ksi). A tempering temperature of 607°C (1125°F) would seem to produce the best results for both transverse and lonitudinal samples as shown in figure 33. Transverse yield would be approximately 903 MPa (131 ksi) with an elongation of 4.0%. Longitudinal yield would be 875 MPa (127 ksi) with an elongation of 14%. These results are the product of a hot rolled, as received condition and should be minimum obtainable.

The following tests were performed on both Republic and Bethlehem Steel. The heat treatment parameters used for these tests were:

Sample size: 3/4" longitudinal
3/4" transverse
Austenitizing Temperature: 815°C (1500°F)
Austenitizing Time: 1 hour
Tempering Temperature: 607°C (1125°F)
Tempering Time: 1 hour
Quench Medium: TexQuench A
Quench Medium Temperature: 65°C (150°F)

Table 13 is a tabulation of the results of testing of Republic Steel. Tables 14 and 15 consist of the Bethlehem test results. The Republic Steel clearly produced a more uniform product than that of Bethlehem.

Figures H1 thru H20 illustrate a composite of a tensile bar, its' fracture and microstructure.

Experimental Problems

In the early stages of the project, the evaluation of as-quenched samples was performed by transporting the samples to the laboratory for metallographic sectioning immediately after austenitization and quench. The samples at this time were at a temperature of 65°C (150°F) to 71°C (160°F). An abrasive cut-off wheel was then used to remove a 1/4 inch section from one end. This operation is performed with the sample under water. Upon mounting these 1/4 inch sections for metallographic evaluation, no visual defects were observed. However, every sample was rejected for processing into tensile bars because of longitudinal cracking which apparently occurred during subsequent tempering. Because of this cracking problem the process was altered to temper all samples for use in tensile testing immediately after quenching.

One as-quenched sample, which had been polished and etched, cracked during metallographic evaluation with enough force to pop off of the inverted stage metallograph.

From these indications it is concluded that HF-1 must be tempered immediately after quenching. No intermediate operations which would subject HF-1 to a liquid medium before tempering should be allowed.

TABLE 15.

HF-1
Republic Steel

Sample	Aust		Temper		Sect.	Yield Sgth		Tensile Sgth		Elong.	RA	Hardness
	°F	°C	°F	°C		(psi)	Mpa	(psi)	Mpa	%	%	Rc
1AA	1500	815	1125	607	L	123005	848	166583	1148	12.0	26.9	33.2
1BA	1500	815	1125	607	L	137327	947	155885	1075	12.0	26.6	32.7
1BD	1500	815	1125	607	L	128860	888	159744	1101	11.0	29.7	34
20AA	1500	815	1125	607	L	120856	833	150802	1040	12.0	25.9	33
20BA	1500	815	1125	607	L	123805	854	164066	1131	12.0	22.8	32.9
20BD	1500	815	1125	607	L	120785	833	168092	1159	12.5	28.3	33.9
40AA	1500	815	1125	607	L	125818	867	165576	1142	12.0	23.5	32.8
40BA	1500	815	1125	607	L	117765	812	169099	1166	12.0	24.9	33.6
40BD	1500	815	1125	607	L	116725	805	166751	1150	12.5	24.6	33.4
1AA	1500	815	1125	607	T	131365	906	157841	1088	4.0	4.7	31
1BA	1500	815	1125	607	T	119654	825	152749	1053	4.5	1.6	31.8
1BD	1500	815	1125	607	T	128309	885	157841	1088	6.0	7.8	30.7
20AA	1500	815	1125	607	T	126685	873	153099	1056	4.5	5.7	32.9
20BA	1500	815	1125	607	T	129940	896	157553	1086	3.5	4.5	30.5
20BD	1500	815	1125	607	T	128309	885	161914	1116	7.0	10.9	31.9
40AA	1500	815	1125	607	T	122199	842	155804	1074	4.0	7.8	32.0
40BA	1500	815	1125	607	T	116090	800	153767	1060	3.0	2.3	31.4
40BD	1500	815	1125	607	T	128819	888	159877	1102	7.0	11.7	32

TABLE 16.

HF-1
Bethlehem Steel

Sample	Aust		Temper		Sect.	Yield Sgth		Tensile Sgth		Elong.	RA	Hardness
	°F	°C	°F	°C		(psi)	Mpa	(psi)	Mpa	%	%	Rc
1T(box)	1500	815	1125	607	T	107658	742	143174	987	3.0	4.6	30.0
1C	1500	815	1125	607	T	122199	842	127800	881	2.0	1.2	32.9
1X	1500	815	1125	607	T	116090	800	149695	1032	3.5	4.0	33
2T	1500	815	1125	607	T	120216	829	147709	1018	4.5	7.3	29.5
2C	1500	815	1125	607	T	125254	864	134929	930	2.0	4.7	31.9
2X	1500	815	1125	607	T	115214	794	149457	1030	4.5	5.0	30.0
10T(box)	1500	815	1125	607	T	115322	795	128316	884	2.0	4.4	31.2
10C	1500	815	1125	607	T	121294	836	142857	985	3.5	2.4	32.3
10X	1500	815	1125	607	T	113034	779	157609	1086	5.5	1.6	29.0
11T	1500	815	1125	607	T	118232	815	149171	1028	3.5	1.7	31.6
11C	1500	815	1125	607	T	120672	832	132383	913	3.0	3.0	30.6
11X	1500	815	1125	607	T	127717	880	153261	1057	3.0	5.7	30.2
19T	1500	815	1125	607	T	115903	799	136927	944	2.5	1.2	29.2
19C	1500	815	1125	607	T	122360	844	129940	896	2.0	6.9	31.6
19X	1500	815	1125	607	T	111051	766	153100	1056	6.0	4.5	30.5
20T(box)	1500	815	1125	607	T	120652	832	141302	974	3.0	2.4	28.8
20C	1500	815	1125	607	T	111532	769	135896	937	3.5	2.0	29.4
20X	1500	815	1125	607	T	108895	751	145553	1003	6.0	6.5	28.3

TABLE 17.

HF-1
Bethlehem Steel

Sample	Aust °F	Aust °C	Temper °F	Temper °C	Sect.	Yield Sgth (psi)	Yield Sgth Mpa	Tensile Sgth (psi)	Tensile Sgth Mpa	Elong. %	RA %	Hardness Rc	
1T(box)	1500	815	1125	607	L	127796	881	154420	1065	10.0	21.2	32	Broke soon @ T.S.
1C	1500	815	1125	607	L	121196	836	154891	1068	9.0	18.1	33.5	
1X	1500	815	1125	607	L	119145	822	165988	1144	8.5	15.3	32.6	
2T	1500	815	1125	607	L	127831	881	166079	1145	10.0	20.0	31.8	
2C	1500	815	1125	607	L	130369	899	161698	1115	10.0	16.0	32.5	
2X	1500	815	1125	607	L	115752	798	160040	1103	12.0	23.5	32.2	
10T(box)	1500	815	1125	607	L	120972	834	159535	1100	8.0	13.0	31.1	bad break
10C	1500	815	1125	607	L	135380	933	163563	1128	11.0	33.0	32.8	
10X	1500	815	1125	607	L	122141	842	160083	1104	8.0	15.1	30.8	
11T	1500	815	1125	607	L	120341	830	158147	1090	9.0	16.9	32.3	bad break @ neck
11C	1500	815	1125	607	L	127174	877	156522	1079	10.0	17.3	30.5	broke @ T.S.
11X	1500	815	1125	607	L	123536	852	158672	1094	9.0	33.0	32.4	
19T	1500	815	1125	607	L	123805	854	158027	1089	6.5	8.9	31.2	
19C	1500	815	1125	607	L	123805	854	160040	1103	9.5	17.1	31.9	
19X	1500	815	1125	607	L	120785	833	157021	1096	12.0	26.2	30.9	
20T(box)	1500	815	1125	607	L	121951	841	159067	1097	7.0	11.9	30.8	
20C	1500	815	1125	607	L	124072	855	154825	1062	8.5	14.1	29.9	
20X	1500	815	1125	607	L	109713	756	149471	1031	12.0	25.6	30.2	

Metallographic Overview

Austenite Grain Size

In order to evaluate the probable reason for the significant variation in mechanical properties of the billets within the heat from Bethlehem Steel and between material from Republic Steel, all samples were etched with Wesley-Austin solution to reveal the prior austenitic grain boundary. The results are listed in Table 16 along with the percent elongation. From the table it can be inferred that larger grain size material generally results in lower elongation values.

It is suggested that the variation in percent elongation in the Bethlehem steel is due to the size of the prior austenitic grain size which is in turn indicative of the method of processing at the steel mill. This means that Bethlehem Steel's single conversion process (rolling from ingot to billet without cooling to room temperature) produces a wide variation in austenitic grain size as opposed to Republic Steel's double conversion (cooling to room temperature in the bloom stage and reheating to complete rolling) which produces a more uniform and smaller grain size. The size of the austenitite grain is dependent on the temperature of the billet during the finish rolling operation and the temperature after the final rolling operation. It is understandable that the grain size of the Bethlehem Steel material is significantly larger than the material from Republic Steel since Bethlehem Steel began their final rolling operation with a billet temperature of 1204°C (2200°F) while Republic Steel's billet temperature was 1121°C (2050°F). The original Bethlehem Steel specification calls out a rolling temperature of 1121°C (2050°F). It is not clear at this time why the Lackawanna Plant of Bethlehem Steel did not adhere to their own specification.

Another reason for lower elongation values, as stated previously is a large amount of undissolved carbide present in the heat treated specimens. It is theorized that the heat treated structure of samples from Republic Steel show a better structure because of the double conversion process. This process produces a pseudo normalizing operation in the process which dissolves the carbides when the blooms are reheated from room temperature to 1121°C (2050°F) prior to final rolling and subsequent air cooling. The carbon content of most of the Bethlehem Steel billets is generally higher than that of Republic Steel's which contribute to the greater quantity of undissolved carbide in the heat treated samples from Bethlehem Steel.

It is therefore postulated that the possibility exists when material from Bethlehem Steel is heated to the proposed forging temperature of 1121°C (2050°F) the structure will be broken up and the mechanical properties will improve with their becoming more uniform. This must be proven and substantiated thru the use of metallographic techniques.

TABLE 18. Comparison of Austenitic Grain Size versus Percent Elongation

Supplier	Location	Figure	ASTM Grain Size No.	Elongation Percent
Republic	1 TOP	J1	4.5	12.0
	1 MID	J2	4	12.0
	1 BOT	J3	3	11.0
	20 TOP	J4	3.5	12.0
	20 MID	J5	5	12.0
	20 BOT	J6	4	12.5
	40 TOP	J7	4.5	12.0
	40 MID	J8	4	12.0
	40 BOT	J9	3.5	12.5
Bethlehem	1 TOP	J10	0	10.0
	1 MID	J11	1	9.0
	1 BOT	J12	0.5	8.5
	2 TOP	J13	1.5	10.0
	2 MID	J14	0	10.0
	2 BOT	J15	2.5	12.0
	10 TOP	J16	1.5	8.0
	10 MID	J17	2	11.0
	10 BOT	J18	1	8.0
	11 TOP	J19	2	9.0
	11 MID	J20	2	10.0
	11 BOT	J21	2	9.0
	19 TOP	J22	1	6.5
	19 MID	J23	1.5	9.5
	19 BOT	J24	3	12.0
	20 TOP	J25	3.5	7.0
	20 MID	J26	2	8.5
	20 BOT	J27	4	12.0

Again, it is indicated that there is no significant difference between Bethlehem Steel's box cooled and furnace cooled material.

Figures J1 through J27 are photomicrographs of the Austentic grain size as contained in Appendix J.

CONCLUSIONS

Alternate Cooling: No significant differences were observed between steel which was furnace cooled and the alternate slow-cooled steel.

Differences in heats: Republic Steel's HF-1 was more consistent in reaching minimum mechanical properties than Bethlehem's. The mean hardness of the Republic steel is higher than that of Bethlehem and significantly more consistent within the heat. In addition, the Republic steel seemed to have a higher hardness in the BD position, which is the middle of the ingot.

Special metallographic techniques must be employed as stated in this report.

HF-1 must be tempered <u>immediately</u> after quenching.

Appendix A

Purchase Orders

PURCHASE ORDER

Chamberlain

Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant
156 Cedar Avenue, Scranton, Pennsylvania 18501
Telephone (717) 342-7801

Jaracki

ORDER DATE: 5/27/80

THE ENTIRE NUMBER BELOW MUST APPEAR ON ALL INVOICES, PACKING SLIPS, CORRESPONDENCE, ETC. REFERRING TO THIS ORDER.

P.O. NO. 9157

PAGE 1 OF 1

ORDERED FROM:

BETHLEHEM STEEL CORPORATION
BETHLEHEM AREA SALES
B106 MARTIN TOWERS
BETHLEHEM, PENNSYLVANIA 18016

DELIVER TO: F/S BILLET YARD

NOTIFY: # 3

DELIVERY REQUIRED IN OUR PLANT: P.O. COMPLETED!

REQUISITION NO	GOV'T CONTRACT NO.	SHIP VIA	ACCOUNT NUMBER
7356	DAAA09-74-C-4009	------------- F.O.B.	PROJECT #7106 1571-493

ITEM	QUANTITY	DESCRIPTION	Date Rec'd	Quantity	Del. Rec. No.
		CHANGE ORDER	6-2-80	Comp	1912-2
		INTERNAL CHANGE ORDER # 2			
		WITH REFERENCE TO THE ABOVE PURCHASE ORDER #, PLEASE REVISE QUANTITY & PRICE TO READ:	X		
		FROM:			
	125 N.T.	HF1 STEEL, BASIC OXYGEN FURNACE HOT ROLLED SEMI-FINISHED FORGING QUALITY FINE GR. 5¼ X 5¼ RCS $503.00/N.T. $62,875.00/LOT	X		DO-A6
		JOMINY TEST REQUIREMENTS $ 2,500.00/LOT	X		
		TO:			
	157.15NT	HF1 STEEL, BASIC OXYGEN FURNACE HOT ROLLED SEMI-FINISHED FORGING QUALITY FINE GR. 5¼ X 5¼ RCS $526.00/N.T. $82,687.90/LOT	X		
		JOMINY TEST REQUIREMENTS $ 2,500.00/LOT			
		NEW TOTAL LOT PRICE $85,187.90	SAAP #329		
			X CERTIFICATIONS MUST BE MAILED SAME DAY SHIPMENT IS MADE.		
PJ/JIC L/Y		EDWARD SOLOWIEJ VICE-PRESIDENT/GENERAL MANAGER DATE:	X		
		PER INV. 80501-485/80501-486 DTD. 11/13/79			

REMARKS:

Figure A1.

PURCHASE ORDER

Chamberlain

Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant
156 Cedar Avenue, Scranton, Pennsylvania 18501
Telephone (717) 342-7801

12/12/79

THE ENTIRE NUMBER BELOW MUST APPEAR ON ALL INVOICES, PACKING SLIPS, CORRESPONDENCE, ETC. REFERRING TO THIS ORDER.

9157

PAGE 1 OF 1

ORDERED FROM	DELIVER TO	DELIVERY REQUIRED IN OUR PLANT
BETHLEHEM STEEL CORPORATION BETHLEHEM AREA SALES B106 MARTIN TOWERS 8TH. & EATON AVENUES BETHLEHEM, PENNSYLVANIA 18016	F/S BILLET YARD NOTIFY # 3	SHIP BY 1/4/80

REQUISITION NO.	GOV'T CONTRACT NO.	SHIP VIA / F.O.B.	ACCOUNT NUMBER
22457	DAAA09-74-C-4009	MILL-FRG. EQUALIZED TO NEAREST PRODUCING PT.	PROJECT 7106 1571-493

ITEM	QUANTITY	DESCRIPTION	Date Rec'd	Quantity	Del. Rec. No.
		CHANGE ORDER	3/11	77645 (114 Pcs)	17837
			3/11	76765 (115 Pcs)	17838
		CHANGE ORDER # 1 WITH REFERENCE TO THE ABOVE PURCHASE ORDER #, PLEASE REVISE MULT WEIGHT TO READ:	X		
				154,410 N.T	
		FROM:	Testing		
		BILLETS TO BE IN MULTIPLES OF 124* LBS. AND NOT TO EXCEED 18' IN LENGTH.	X	157.15	N.T DO-A6
		TO:			
		BILLETS TO BE IN MULTIPLES OF 80* LBS. AND NOT TO EXCEED 18' IN LENGTH.	X		
		*RESERVE OPTION TO CHANGE WEIGHT PRIOR TO ROLLING.	Pre.	14,812.90	
		BALANCE OF ORDER TO REMAIN THE SAME.	X		
		82687.90 testing 2500.– 85,187.90			
			CERTIFICATIONS MUST BE MAILED SAME DAY SHIPMENT IS MADE.		
JPJ/JIC L/Y		PENNSYLVANIA STATE TAX DOES NOT APPLY.	SAAP # 329		

REMARKS:

Figure A2.

Chamberlain

Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant
156 Cedar Avenue, Scranton, Pennsylvania 18501
Telephone (717) 342-7801

12/7/79

11/15/79

THE ENTIRE NUMBER BELOW MUST APPEAR ON ALL INVOICES, PACKING SLIPS, CORRESPONDENCE, ETC REFERRING TO THIS ORDER

P.O. NO. 0157

PAGE 1 OF 3

BETHLEHEM STEEL CORPORATION
BETHLEHEM AREA SALES
B106 MARTIN TOWERS
8TH. & EATON AVENUES
BETHLEHEM, PENNSYLVANIA 18016

DELIVER TO	DELIVERY REQUIRED IN OUR PLANT
F/S BILLET YD.	SHIP BY 1/4/80
NOTIFY: # 3	

REQUISITION NO.	GOV'T CONTRACT NO.	SHIP VIA / F.O.B.	ACCOUNT NUMBER
2355	DAAA09-74-C-4089	MILL-FREIGHT EQUALIZED TO NEAREST PROD. POINT	PROJECT 7106 1571-493

QUANTITY	DESCRIPTION	Date Rec'd	Quantity	Del. Rec. No.
1 HEAT (EST.WT.) (125N.T.)	HF1 STEEL, BASIC OXYGEN FURNACE, HOT ROLLED, SEMI-FINISHED, FORGING QUALITY, FINE GRAIN 5½ X 5½ R.C.S. IN ACCORDANCE WITH SPECIFICATION MIL-S-50783 DATED 20 SEPT. 1973. CORNER RADIUS TO BE .75 OR 3/4" DIAGONAL: 6.840 + .090 INCHES.	X		
	$503.00/N.T. $62,875.00/LOT			
	ONE TIME CHARGE FOR JOMINY TEST REQUIREMENT.	X	~~DO-A5~~	
	$2,500.00 $ 2,500.00/LOT			
	TOTAL LOT PRICE $65,375.00	X		
157.15 NT	1. BILLETS TO BE IN MULTIPLES OF ~~224~~* LBS. 80# AND NOT TO EXCEED 18' IN LGTH. SHORT BILLETS PERMITTED IN MULTIPLES OF 124* LBS. *RESERVE OPTION TO CHANGE WEIGHT PRIOR TO ROLLING.	X	SAAP # 329	
	2. EACH BILLET SHALL BE PERMANENTLY MARKED TO IDENTIFY:			
	A. HEAT DESIGNATION	X	CERTIFICATIONS MUST BE MAILED SAME DAY SHIPMENT IS MADE.	
	B. INGOT NUMBER FROM WHICH ROLLED			
/JIC	C. LOCATION WITHIN INGOT, I.E. 1ST., 2ND., 3RD., ETC.			

KS:

Figure A3.

CHAMBERLAIN MANUFACTURI(ORP.
SCRANTON, PENNSYLVANIA 18501

CONTINUATION SHEET NO. 3 OF 3

VENDOR BETHLEHEM STEEL CORP. OF PURCHASE ORDER NO. 9157

EM	QUANTITY	DESCRIPTION	Date Rec'd	Quantity	Del Re
		3. COOLING A. THE MATERIAL FROM THE FIRST, MIDDLE AND LAST USABLE INGOTS OF THE HEAT WILL BE SLOW-COOLED BY A METHOD OTHER THAN FURNACE. SPECIFY METHOD. B. THE MATERIAL FROM ALL OTHER INGOTS WILL BE COOLED BY YOUR CONVENTIONAL FURNACE COOLING PRODEDURE FOR THIS STEEL ALLOY. 4. CERTIFICATION OF CHEMISTRY, IN ACCORDANCE WITH MIL-S-50783, WILL BE FURNISHED AND WILL INCLUDE: A. LADLE ANALYSIS B. CHECK ANALYSIS OF 1ST., MIDDLE AND LAST USABLE INGOTS. C. CHECK ANALYSIS OF 2ND., 1ST. AFTER MIDDLE, AND NEXT TO LAST INGOTS. 5. JOMINY HARDENABILITY TESTS ON MATERIAL WILL BE MADE AND IDENTIFIED TO THE 1ST., 2ND., MIDDLE, 1ST. AFTER MIDDLE, NEXT TO LAST, AND LAST USABLE INGOTS (6 INGOTS). THREE JOMINY TESTS EACH INGOT REPRESENTING THE TOP, MIDDLE AND BOTTOM OF EACH INGOT. THE RESULTS OF THE JOMINY TESTS WILL BE CERTIFIED; THE TEST BARS AND DATA WILL BE FURNISHED TO THE CUSTOMER. TESTS TO BE IN ACCORDANCE WITH ASTM-A-255. 6. AT TIME OF SHIPMENT, AN INVENTORY OF THE HEAT WILL BE FURNISHED TO THE BUYER CONSISTING			

REMARKS:

Figure A4.

PURCHASING - EXPEDITER COPY

CHAMBERLAIN MANUFACTURING CORP.
SCRANTON, PENNSYLVANIA 18501

CONTINUATION SHEET NO 3 OF 3

VENDOR BETHLEHEM STEEL CORP. OF PURCHASE ORDER NO. 9157

EM	QUANTITY	DESCRIPTION	Date Rec'd	Quantity	Del Rec No
		OF: A. HEAT IDENTIFICATION NUMBER B. NUMBER OF INGOTS IN HEAT C. IDENTIFICATION, BY INGOT NUMBER, OF THOSE INGOTS COOLED AS IN 5A. ABOVE, DESCRIPTION OF AND METHOD OF COOLING D. METHOD OF CONVENTIONAL COOLING OF BALANCE OF BILLETS; COMPLETE DESCRIPTION E. NUMBER OF BILLETS FROM EACH INGOT F. OTHER DATA CONSIDERED PERTINENT			
		7. SELLER WILL NOTIFY BUYER OF THE TIME/DATE OF PRODUCING THIS HEAT SO THAT ARRANGEMENTS CAN BE MADE FOR BUYER'S AND/OR GOVERNMENT REPRESENTATIVES TO BE PRESENT DURING THE PERIOD.			
		8. THIS MATERIAL WILL BE USED IN PERFORMANCE OF A MM & T TEST PROGRAM UNDER A GOVERNMENT CONTRACT # DAAA09-74-C-4089. IT IS DESIRED THAT YOUR NORMAL, ROUTINE PRACTICES IN HANDLING THIS MATERIAL BE ADHERED TO AND THAT NO SPECIAL PROCESSING, OTHER THAN DETAILED ABOVE, BE EMPLOYED.			
		Edward Solowiej EDWARD SOLOWIEJ VICE-PRESIDENT/GENERAL MANAGER DATE: 11-16-77			
		PENNSYLVANIA STATE TAX DOES NOT APPLY. ENCLOSURES: AFFIRMATIVE ACTION FOR HANDICAPPED WORKERS EQUAL EMPLYMENT OPPORTUNITY CERT. OF EQUAL EMPLOYMENT COMPLIANCE			

REMARKS:
CERT. OF NON-SEGREGATED FACILITIES
AFF. ACTION FOR DISABLED VETS & VETS OF VIETNAM
CLEAN AIR & WATER CERTIFICATION
AFFIRMATIVE ACTION PROGRAM

Figure A5.

PURCHASING - EXPEDITER COPY

PURCHASE ORDER

Chamberlain

Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant
156 Cedar Avenue, Scranton, Pennsylvania 18501
Telephone (717) 342-7801

ORDER DATE: 12/12/79

THE ENTIRE NUMBER BELOW MUST APPEAR ON ALL INVOICES, PACKING SLIPS, CORRESPONDENCE, ETC. REFERRING TO THIS ORDER.

P.O. NO. 9158

PAGE 1 OF 1

	DELIVER TO	DELIVERY REQUIRED IN OUR PLANT
REPUBLIC STEEL CORPORATION 10 VALLEY FORGE EXECUTIVE MALL 530 SWEDESFORD ROAD WAYNE, PENNSYLVANIA 19087	F/S BILLET YD. NOTIFY # 3	SHIP BY 1/4/80

REQUISITION NO.	GOV'T CONTRACT NO.	SHIP VIA / F.O.B.	ACCOUNT NUMBER
22456	DAAA09-74-C-4009	MILL-FRT. EQUALIZED TO NEAREST PROD. POINT	PROJECT 7106 1571-493

ITEM	QUANTITY	DESCRIPTION	Date Rec'd	Quantity	Del. Rec. No.
		CHANGE ORDER	2-20-80	9 Pcs Test	17204
		CHANGE ORDER # 1 WITH REFERENCE TO THE ABOVE PURCHASE ORDER #, PLEASE REVISE MULT WEIGHT TO READ:	X		
		FROM:	X		
		BILLETS TO BE IN MULTIPLES OF 124* LBS. AND NOT TO EXCEED 18' IN LENGTH			DG-AS
		TO:			
		BILLETS TO BE IN MULTIPLES OF 80* LBS. AND NOT TO EXCEED 18' IN LENGTH.	X		
		*RESERVE OPTION TO REVISE WEIGHT PRIOR TO ROLLING			
		BALANCE OF ORDER TO REMAIN THE SAME	X		
			CERTIFICATIONS TO BE MAILED SAME DAY SHIPMENT		
			X IS MADE.		
JPJ/JIC 1		PENNSYLVANIA STATE TAX DOES NOT APPLY.	SAAP # 323		

REMARKS:

Figure A6.

Chamberlain

Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant
156 Cedar Avenue, Scranton, Pennsylvania 18501
Telephone (717) 342-7801

11/13/79

THE ENTIRE NUMBER BELOW MUST APPEAR ON ALL INVOICES, PACKING SLIPS, CORRESPONDENCE, ETC. REFERRING TO THIS ORDER

P.O. NO. 9158

PAGE 1 OF 3

REPUBLIC STEEL CORPORATION
10 VALLEY FORGE EXECUTIVE MALL
530 SWEDESFORD ROAD
WAYNE, PENNSYLVANIA 19087

DELIVER TO	DELIVERY REQUIRED IN OUR PLANT
F/S BILLET YD	SHIP BY 1/4/80
NOTIFY # 3	

...ITION NO.	GOV'T CONTRACT NO.	SHIP VIA / F.O.B.	ACCOUNT NUMBER
2354	DAAA09-74-C-4009	MILL-FREIGHT EQUALIZED TO NEAREST PROD. POINT	PROJ. 7105 1571-493

QUANTITY	DESCRIPTION	Date Rec'd	Quantity	Del. Rec. No.
1 HEAT (EST.WT. 200 NT)	HF1 STEEL, BASIC OXYGEN FURNACE, HOT ROLLED, SEMI-FINISHED, FORGING QUALITY, FINE GRAIN 5½ X 5½ R.C.S. IN ACCORDANCE WITH SPECIFICATION MIL-S-50783 DATED 20 SEPT. 1973. CORNER RADIUS TO BE .75 OR 3/4" DIAGONAL: 6.840 ± .090 INCHES.	1-11	3 Pcs	16269 (9x.)
		1-21	126	16435
		1-21	109	16436
		X		
	PRICE PER YOUR QUOTATION OF 23 AUG. 1979 $25.00/CWT. $100,000.00/LT.	X		DO-A5
	1. BILLETS ARE TO BE IN MULTIPLES OF 124* 80# LBS. AND NOT TO EXCEED 18' IN LGTH. SHORT BILLETS PERMITTED IN MULTIPLES OF 124* LBS. *RESERVE OPTION TO CHANGE WEIGHT PRIOR TO ROLLING.	X		
		X	SAAP # 328	
	2. EACH BILLET SHALL BE PERMANENTLY MARKED TO IDENTIFY: A. HEAT DESIGNATION B. INGOT NUMBER FROM WHICH ROLLED C. LOCATION WITHIN INGOT, I.E. 1ST., 2ND., 3RD., ETC.	X	CERTIFICATIONS MUST BE ~~MAILED SAME DAY SHIPMENT~~ IS MADE.	
/JIC	3. COOLING. THE MATERIAL WILL BE SLOW-		CONTINUED ON PAGE 2	

11/27/79 Mult wt for FOR 549 W/HEAD 80# PER H. KRINKEL TELCON

...RKS: 7.672 C# WT PER LINEAL INCH

MULT LENGTH 10.427"

Figure A7.

PURCHASING - EXPEDITE COPY

CHAMBERLAIN MANUFACTURI(CORP.
SCRANTON, PENNSYLVANIA 18501

CONTINUATION SHEET NO. 2 OF 3

VENDOR REPUBLIC STEEL CORPORATION

OF PURCHASE ORDER NO. 9158

EM	QUANTITY	DESCRIPTION	Date Rec'd	Quantity	Del Re
		COOLED BY YOUR USUAL PIT COOLING PROCEDURE.			

4. CERTIFICATION OF CHEMISTRY IN ACCORDANCE WITH MIL-S-50783 WILL BE FURNISHED AND WILL INCLUDE:
   A. LADLE ANALYSIS
   B. CHECK ANALYSIS OF 1ST., MIDDLE AND LAST USABLE INGOTS.

5. JOMINY HARDENABILITY TESTS ON MATERIAL WILL BE MADE AND IDENTIFIED TO THE 1ST., MIDDLE AND LAST USABLE INGOTS (3 INGOTS). THREE JOMINY TESTS WILL BE MADE ON MATERIAL FROM EACH INGOT REPRESENTING THE TOP, MIDDLE AND BOTTOM OF EACH INGOT.

THE RESULTS OF THE JOMINY TESTS WILL BE CERTIFIED; THE TEST BARS AND DATA WILL BE FURNISHED TO THE CUSTOMER. JOMINY TESTS TO BE IN ACCORDANCE WITH ASTM-A-255.

6. AT TIME OF SHIPMENT, AN INVENTORY OF THE HEAT WILL BE FURNISHED TO BUYER, CONSISTING OF:
   A. HEAT IDENTIFICATION NUMBER
   B. NUMBER OF INGOTS IN HEAT
   C. DESCRIPTION, COMPLETE, OF COOLING METHOD USED
   D. NUMBER OF BILLETS FROM EACH INGOT.
   E. OTHER DATA CONSIDERED PERTINENT

REMARKS:

Figure A8.

PURCHASING EXPEDITER COPY

CHAMBERLAIN MANUFACTURI(.ORP.
SCRANTON, PENNSYLVANIA 18501

CONTINUATION SHEET NO. 3 OF 3

VENDOR REPUBLIC STEEL CORPORATION OF PURCHASE ORDER NO. 9 1 5 8

M	QUANTITY	DESCRIPTION	Date Rec'd	Quantity	Del Rec No
		7. SELLER WILL NOTIFY BUYER OF THE TIME/DATE OF PRODUCING THIS HEAT OF STEEL SO THAT ARRANGEMENTS CAN BE MADE FOR BUYER'S AND/OR GOVERNMENT REPRESENTATIVES TO BE PRESENT DURING THIS PERIOD.			
		8. THIS MATERIAL WILL BE USED IN PERFORMANCE OF A MM & T TEST PROGRAM UNDER A GOVERNMENT CONTRACT #DAAA09-74-C-4009. IT IS DESIRED THAT YOUR NORMAL, ROUTINE, PRACTICES IN HANDLING THIS MATERIAL BE ADHERED TO AND THAT NO SPECIAL PROCESSING, OTHER THAN DETAILED ABOVE, BE EMPLOYED.			
		Edward Solowiej EDWARD SOLOWIEJ VICE-PRESIDENT/GENERAL MANAGER DATE: 11-16-73			
		PENNSYLVANIA STATE TAX DOES NOT APPLY.			
		ENCLOSURES: AFFIRMATIVE ACTION FOR HANDICAPPED WORKERS EQUAL EMPLOYMENT OPPORTUNITY CERTIFICATE OF EQUAL EMPLOYMENT COMPLIANCE CERTIFICATE OF NON-SEGREGATED FACILITIES AFF. ACTION FOR DISABLED VETS & VETS OF VIETNAM CLEAN AIR AND WATER CERTIFICATION AFFIRMATIVE ACTION PROGRAM COST ACCOUNTING STDS. P:2 91-379 DISCLOSURE STATEMENT CERTIFICATE OF CURRENT COST OR PRICING DATE			

REMARKS:

Figure A9.

PURCHASING - EXPEDITER COPY

Appendix B

Photographs of Process

HF-1

Republic Steel

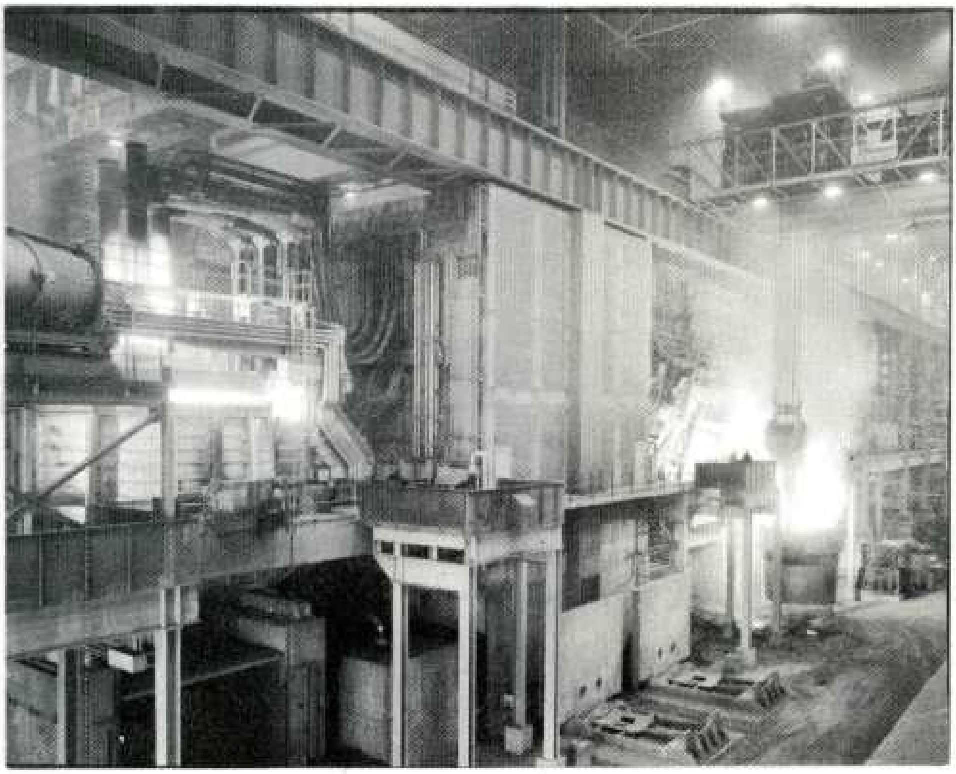


Figure B1. Electric Furnaces

Republic Steel

Figure B2. Bottom Pour Ladle

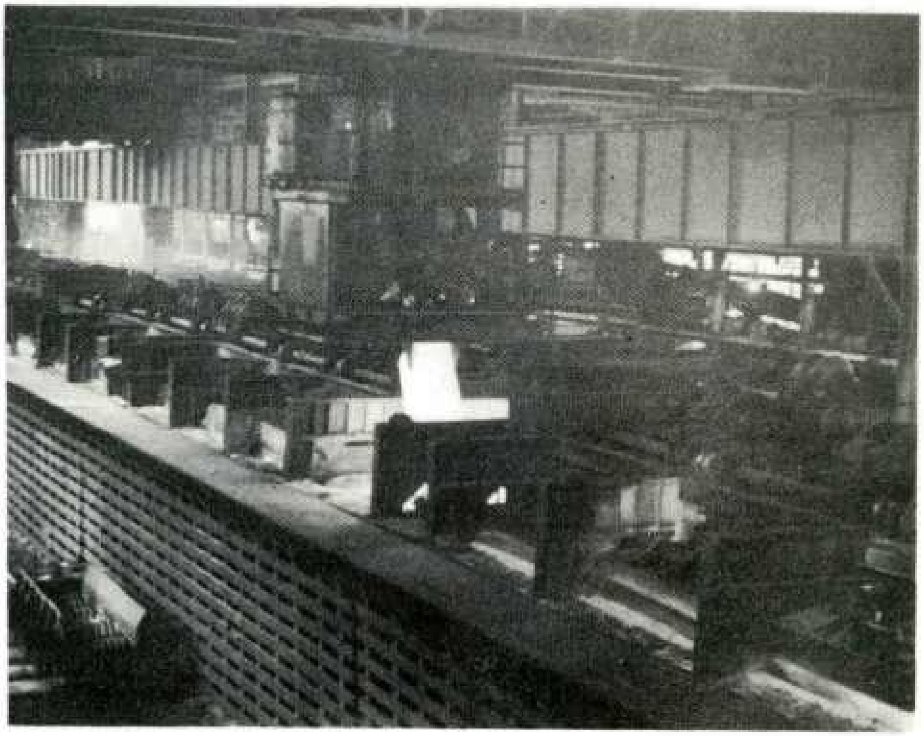


Figure B3. Ingot being Removed from Soaking Pits

Republic Steel

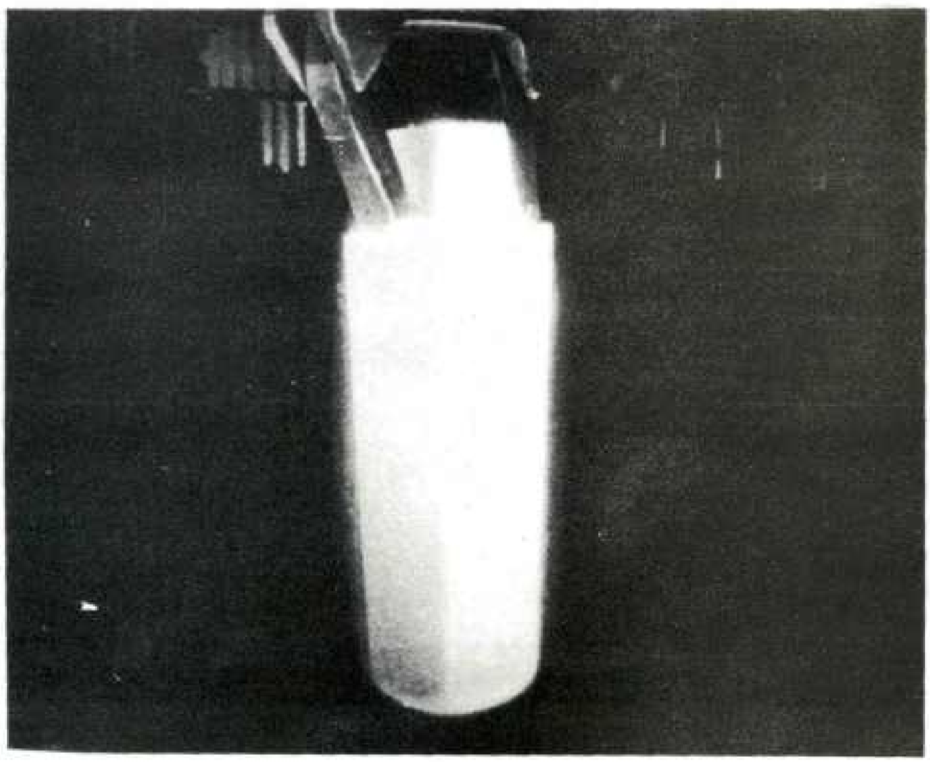


Figure B4. Ingot Being Transported to Blooming Mill

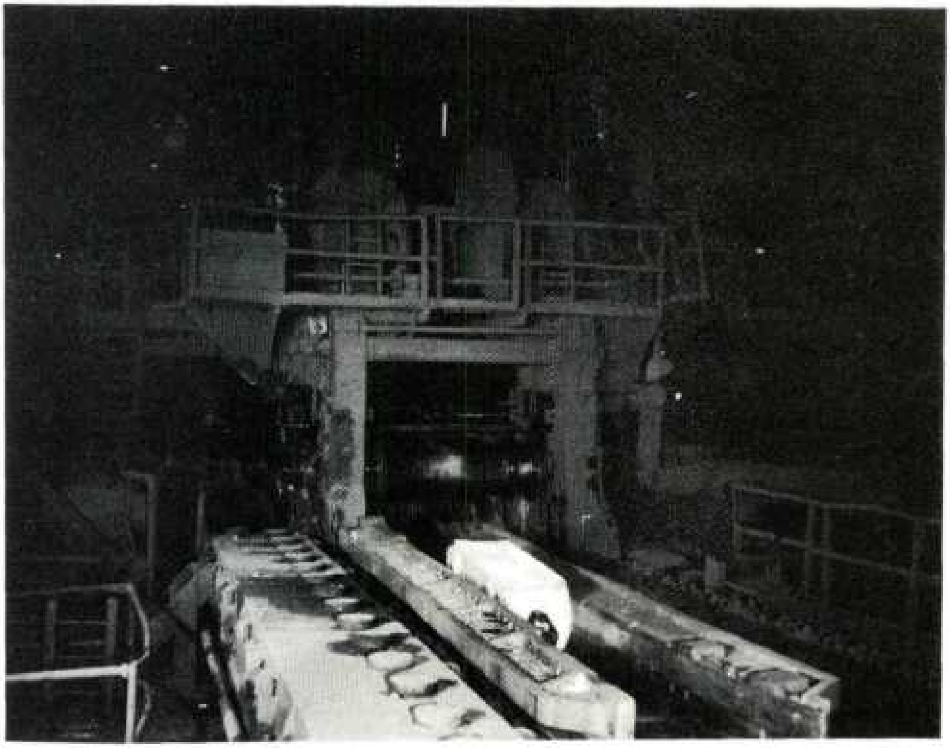


Figure B5. Ingot Being Rolled in 35 inch Blooming Mill

Republic Steel

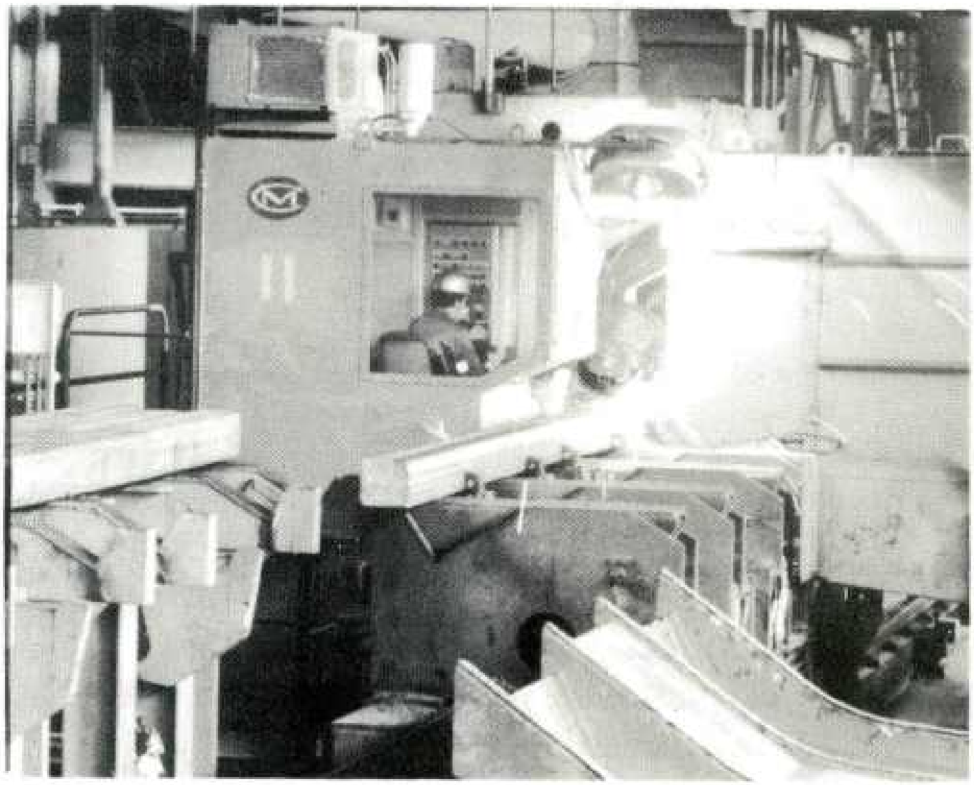


Figure B6. Grinding Blooms

HF-1

Republic Steel

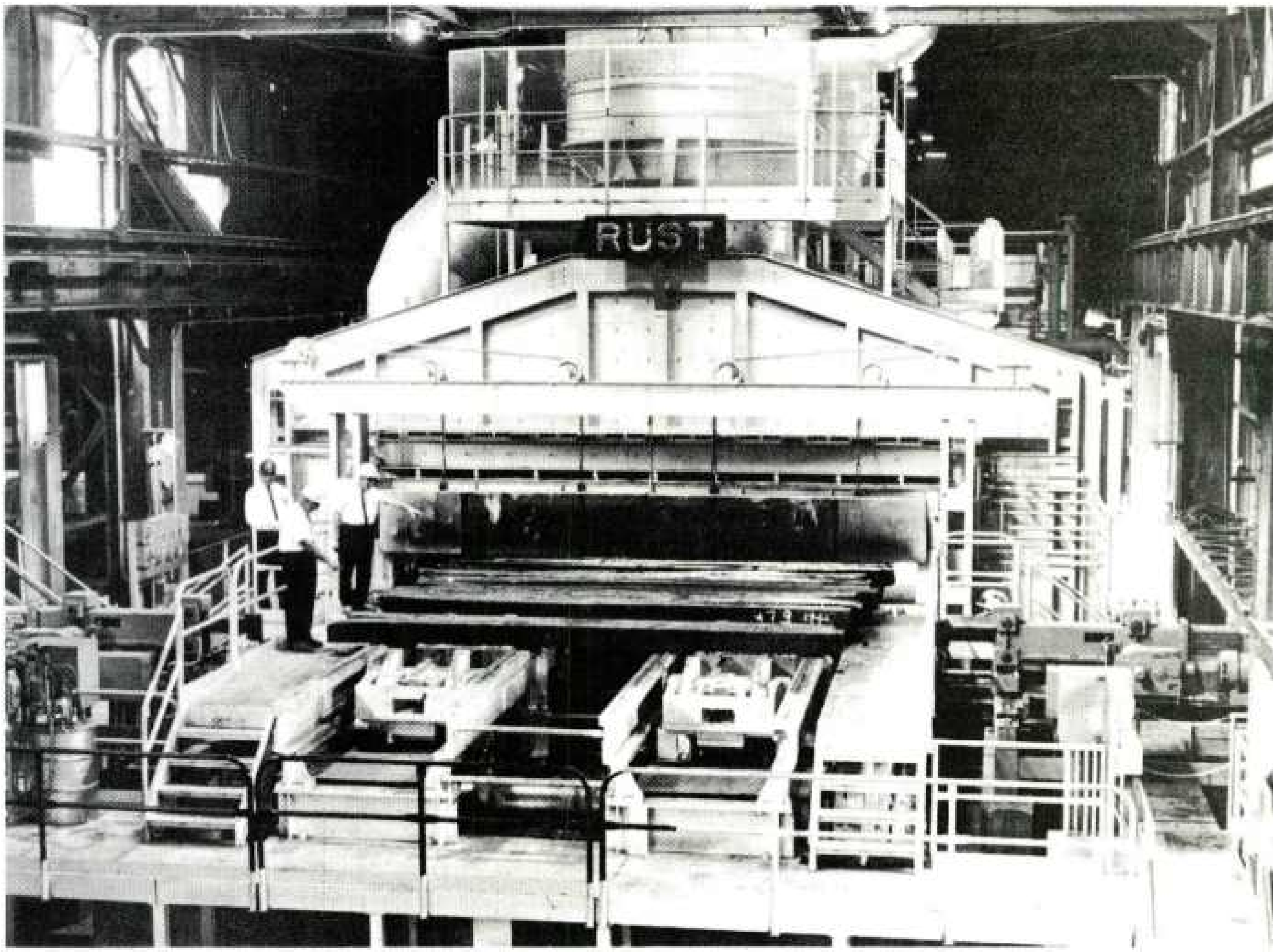


Figure B7. Bloom Reheat Furnace

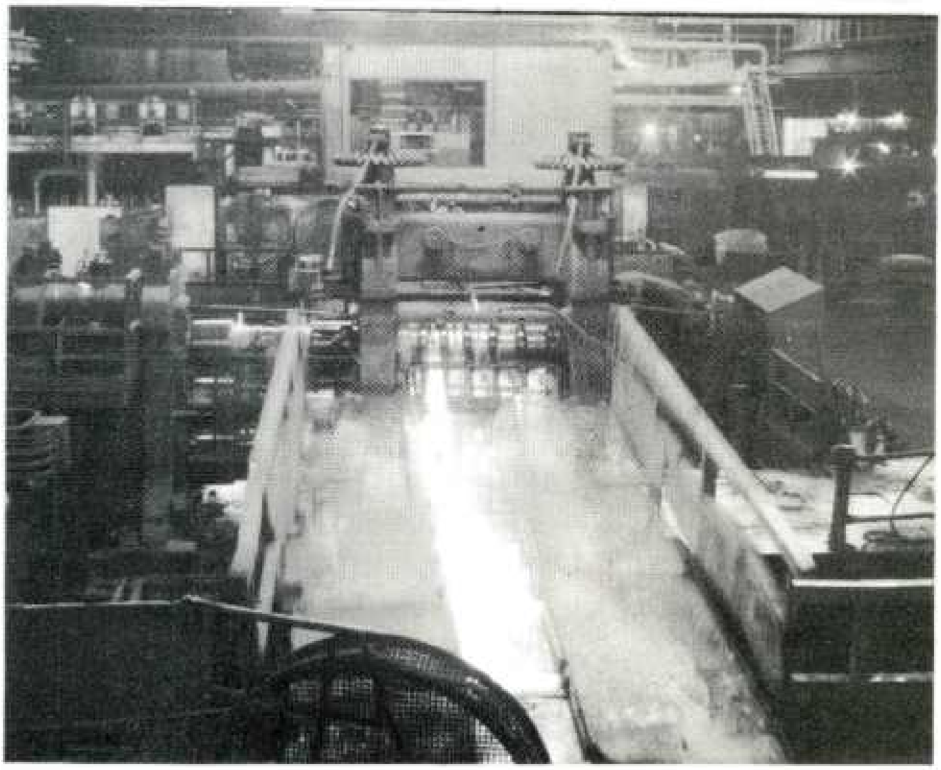


Figure B8. Exit Side: Seven Pass Reversing Mill

Republic Steel

Figure B9. Exit Side: Finish Roll Stand

HF-1

Republic Steel

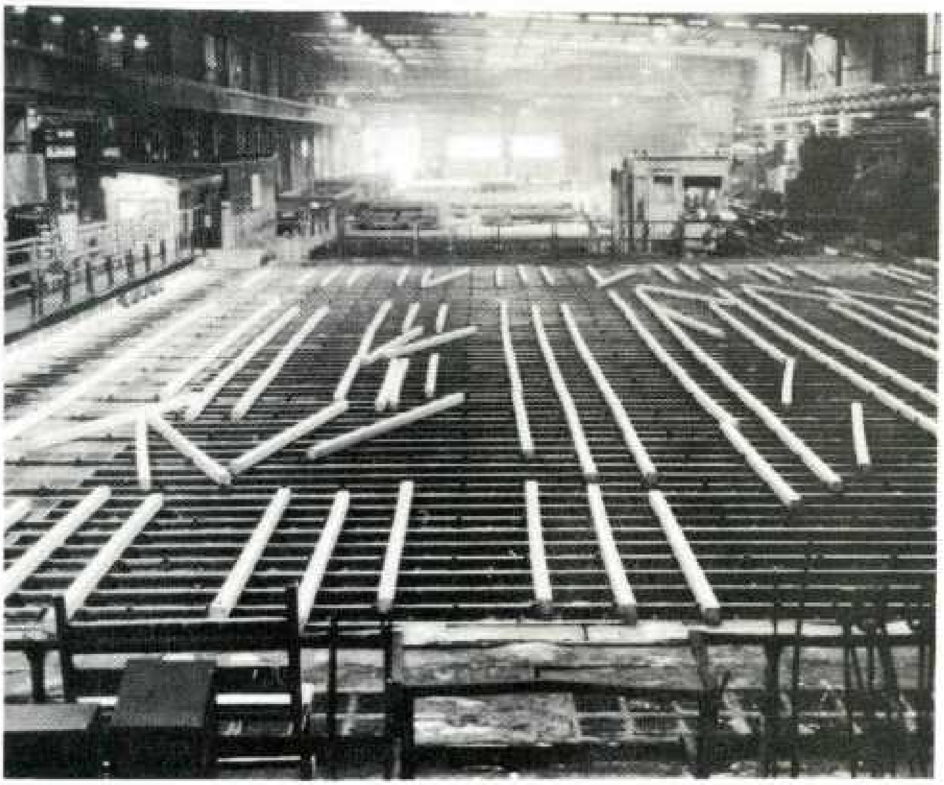


Figure B10 Run-Out Table for Preliminary Cooling Prior to Pit Cooling

Republic Steel

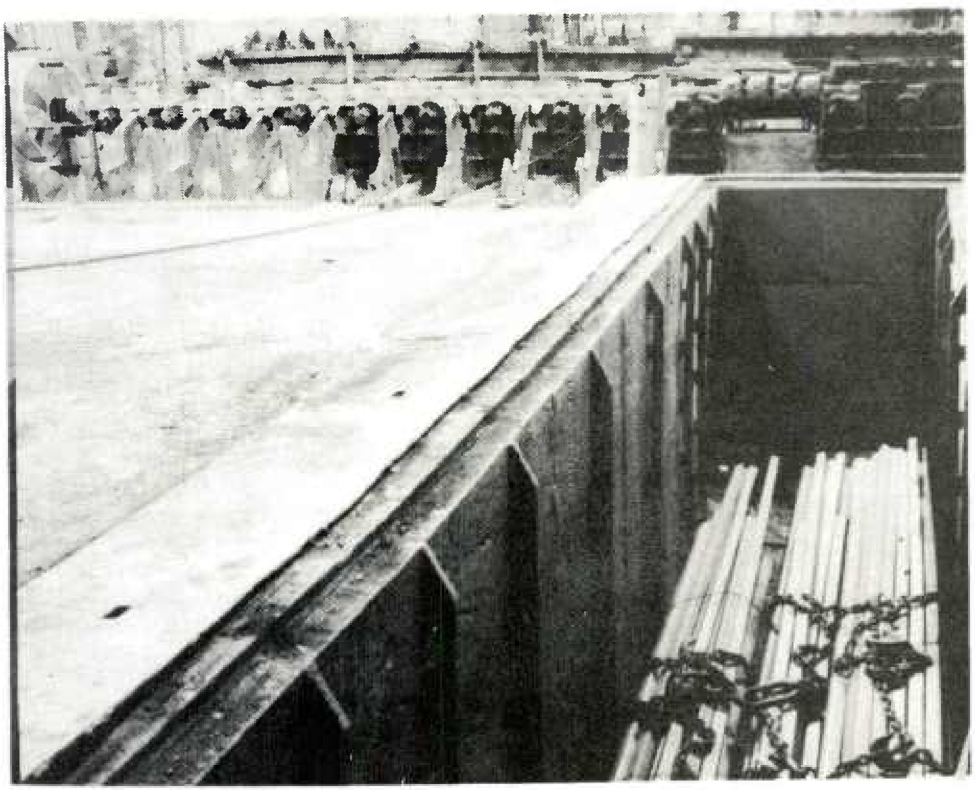


Figure B11. Billets in Cooling Pit

HF-1

Bethlehem Steel

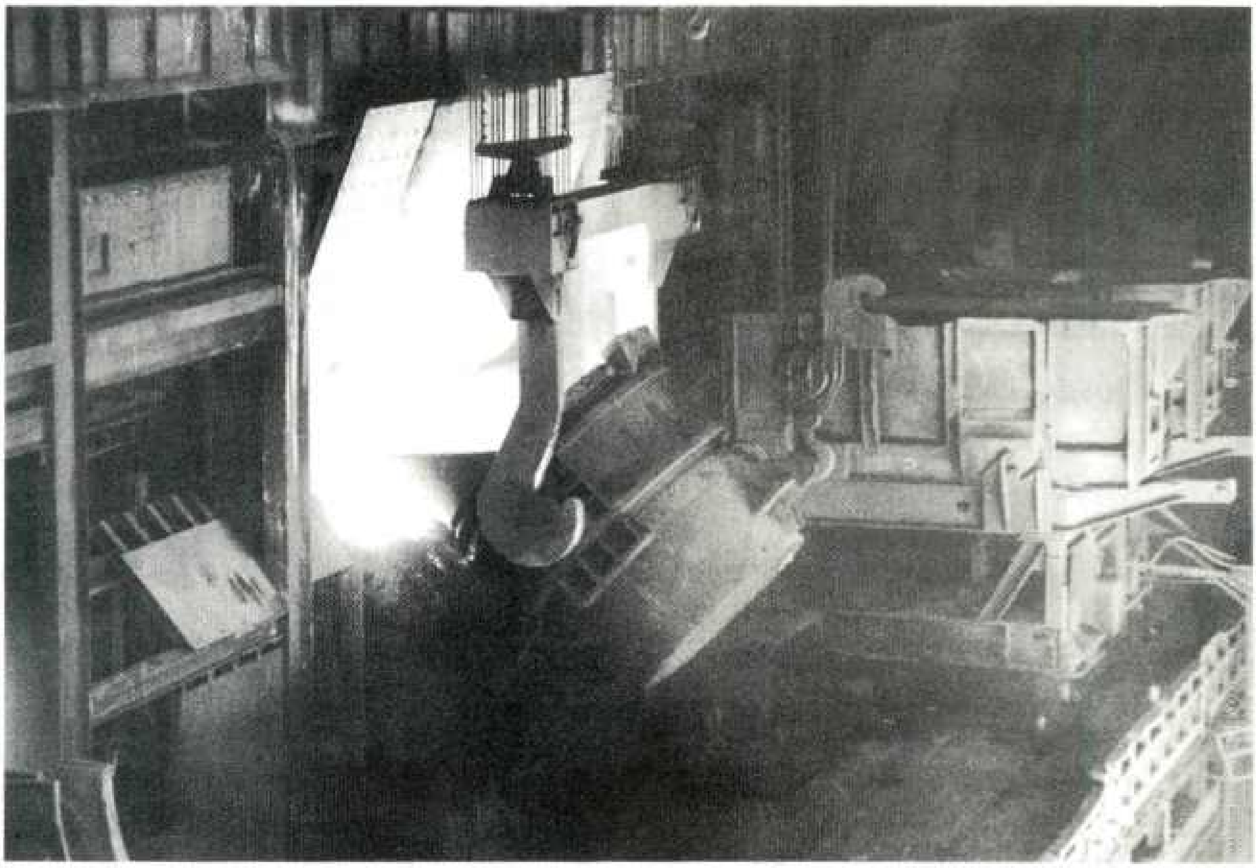


Figure B12. Charging the BOF with Liquid Metal

HF-1

Bethlehem Steel

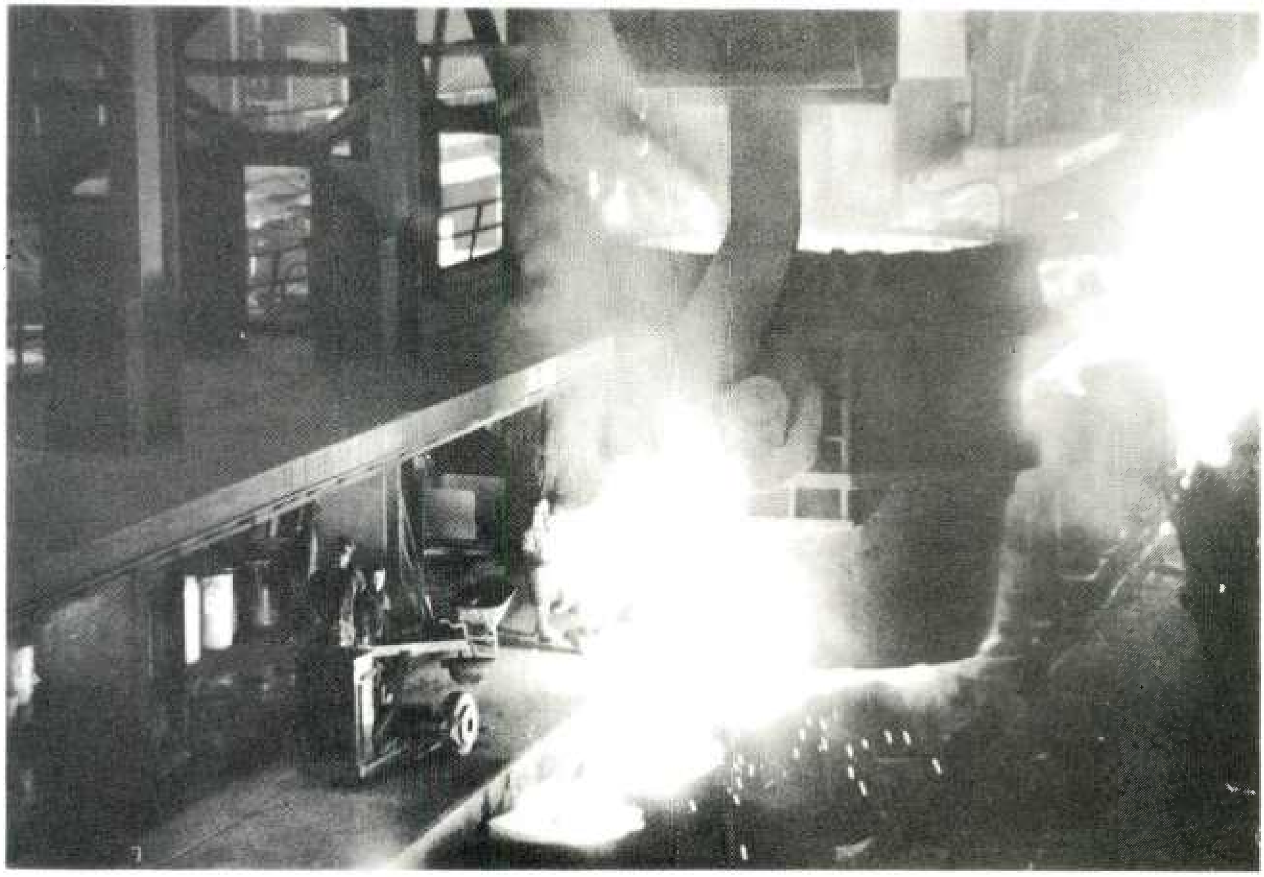


Figure B13. Method of Teeming Ingots from A Bottom Pour Ladle

Bethlehem Steel

Figure B14. Stripping Molds from Ingots

Bethlehem Steel

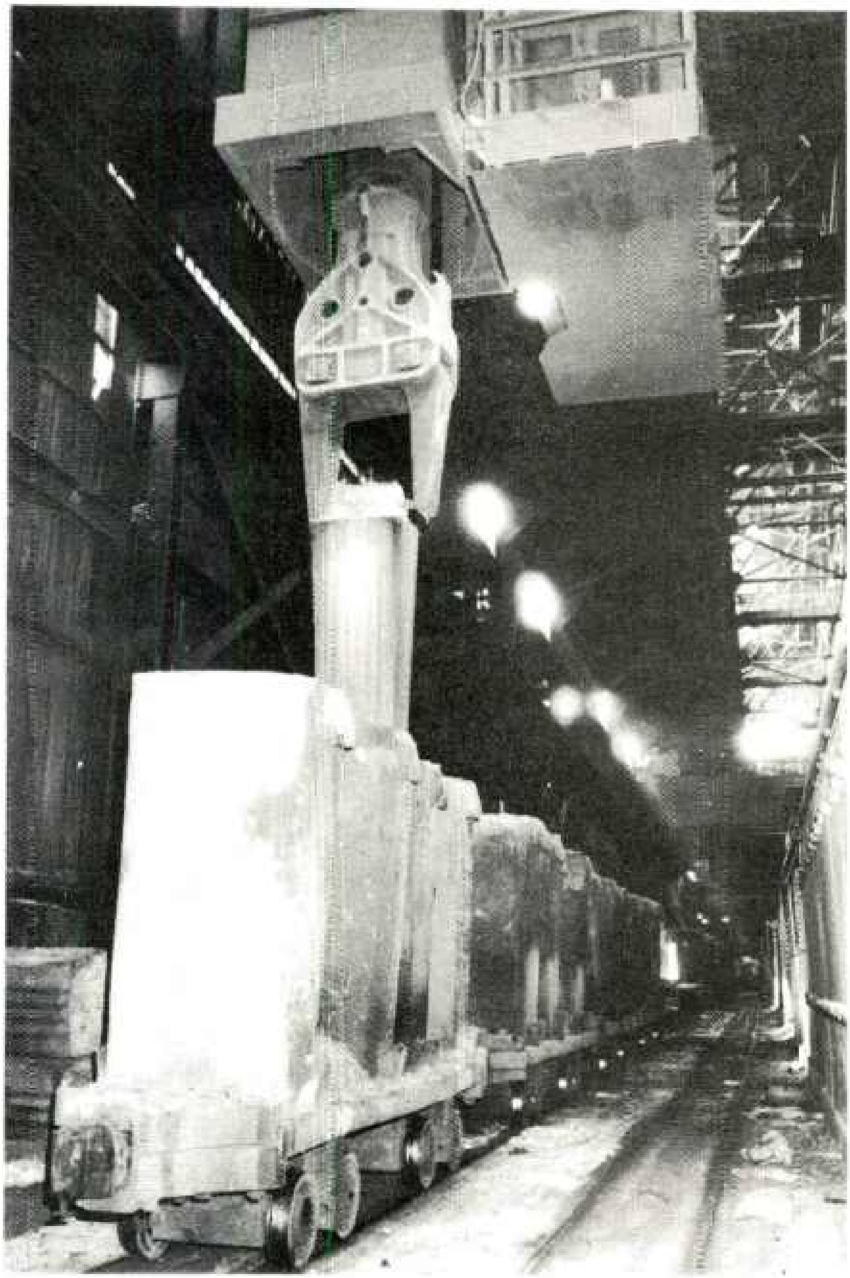


Figure B15. Preparing to charge ingots into soaking pits

Bethlehem Steel

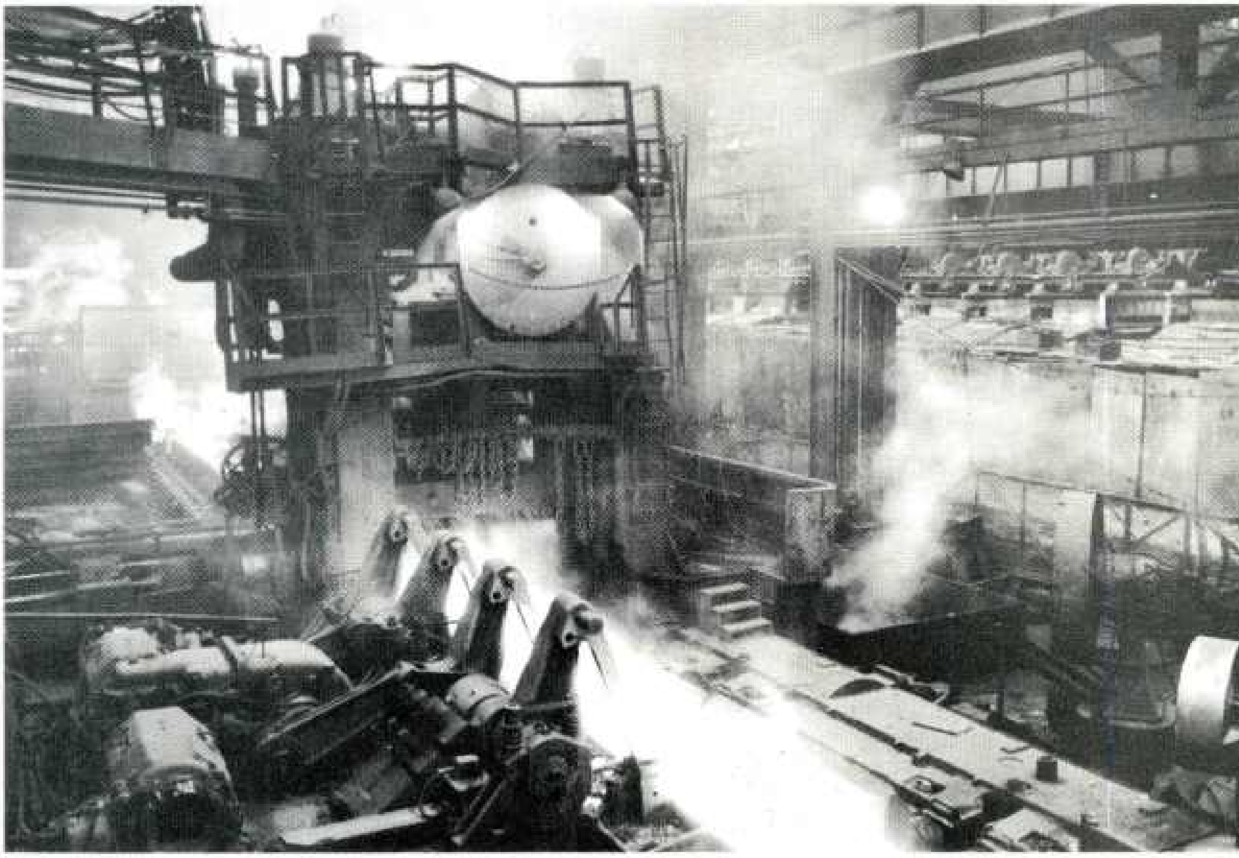


Figure B16. 44 inch Blooming Mill

HF-1

Bethlehem Steel

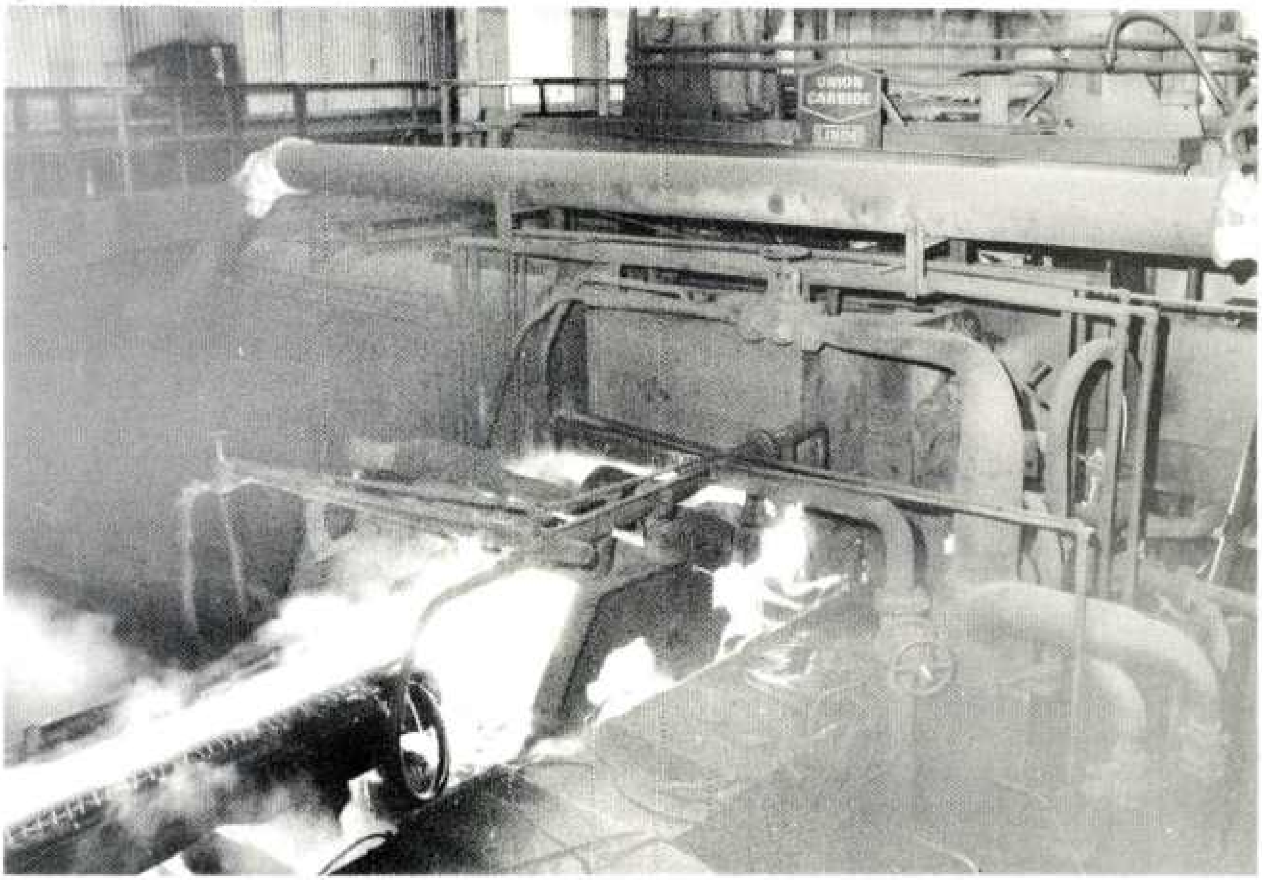


Figure B17. 44 inch Scarfer Removing Surface Defects

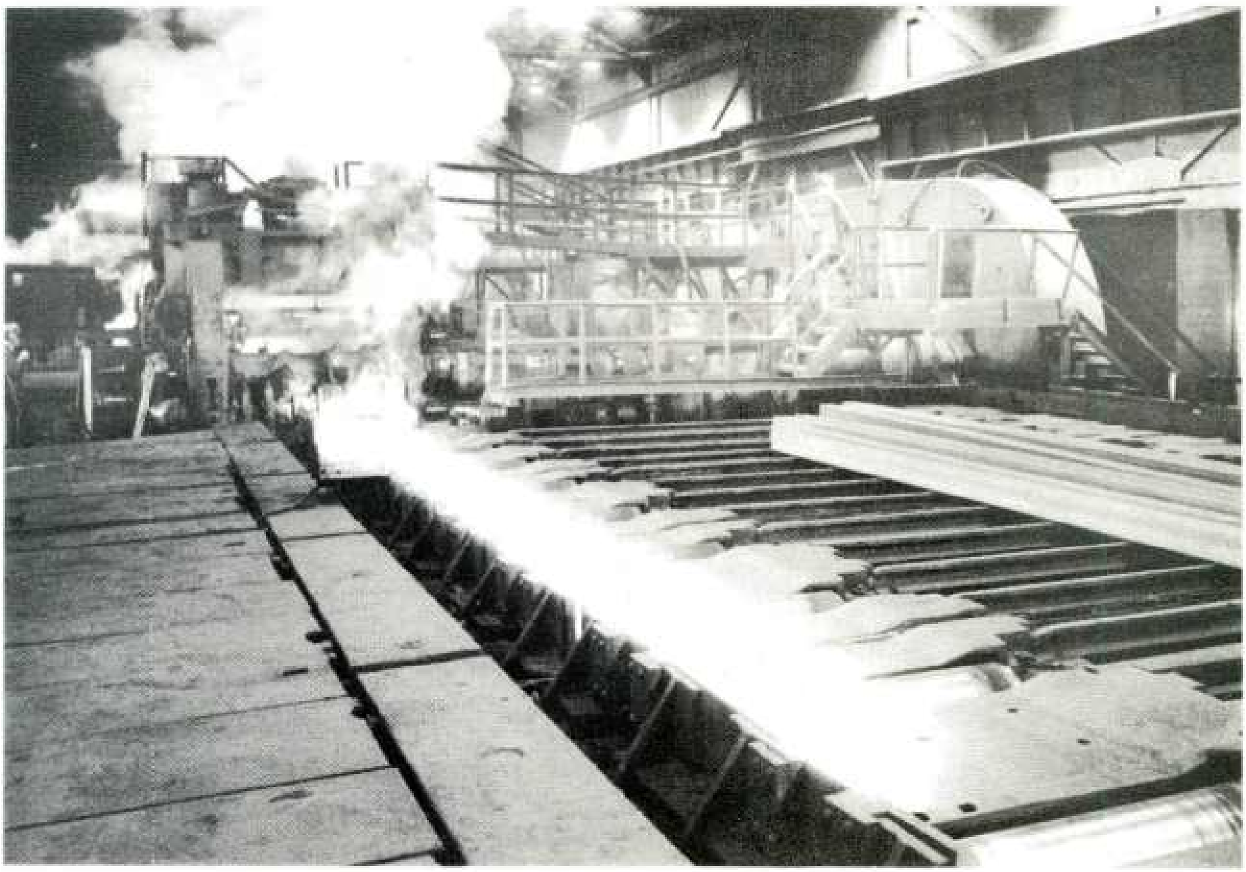


Figure B18. 30 inch Billet Mill

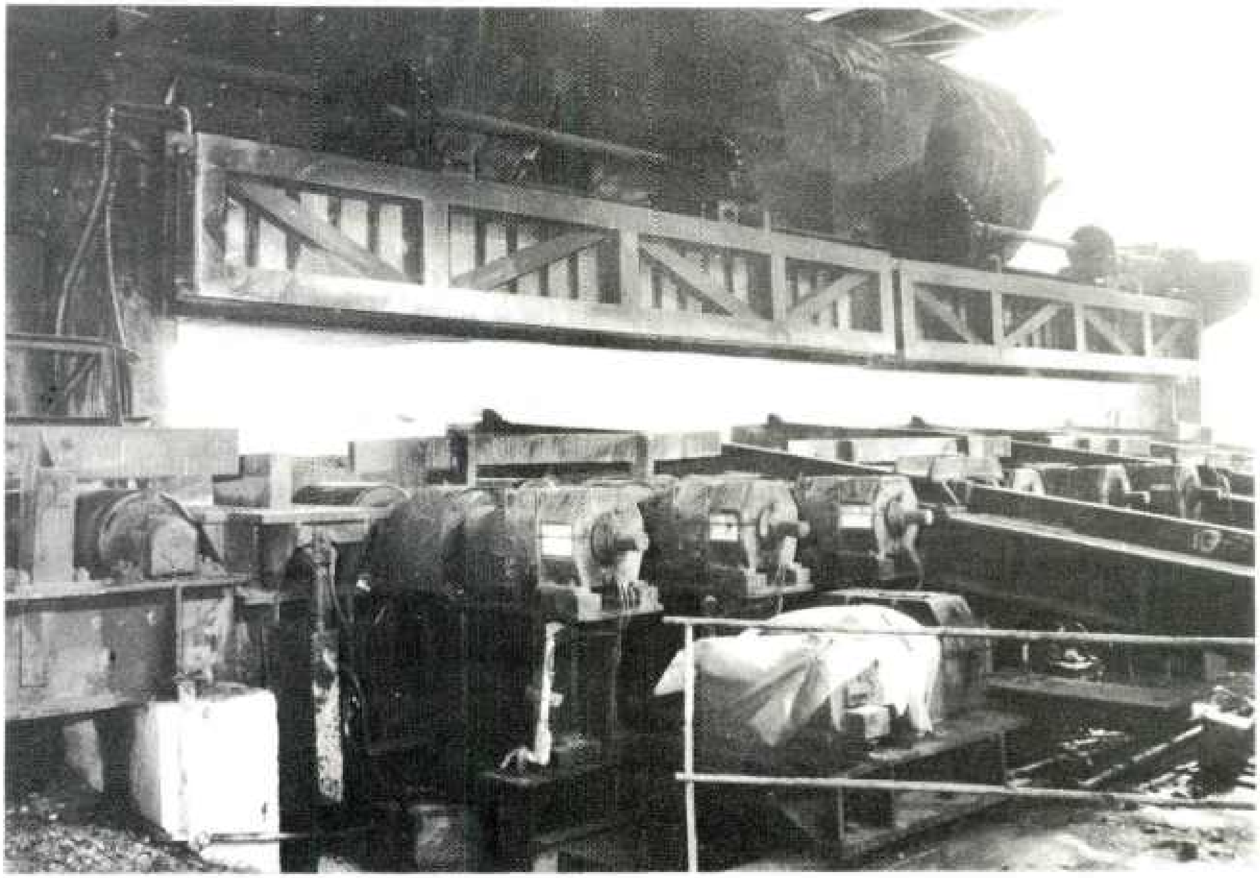


Figure B19. Reheat Furnace Between the 30 inch Billet Mill and the 21 inch Billet Mill

Figure B20. 21 inch Billet Mill Which Reduces Billets to Final 5 1/4 inch size.

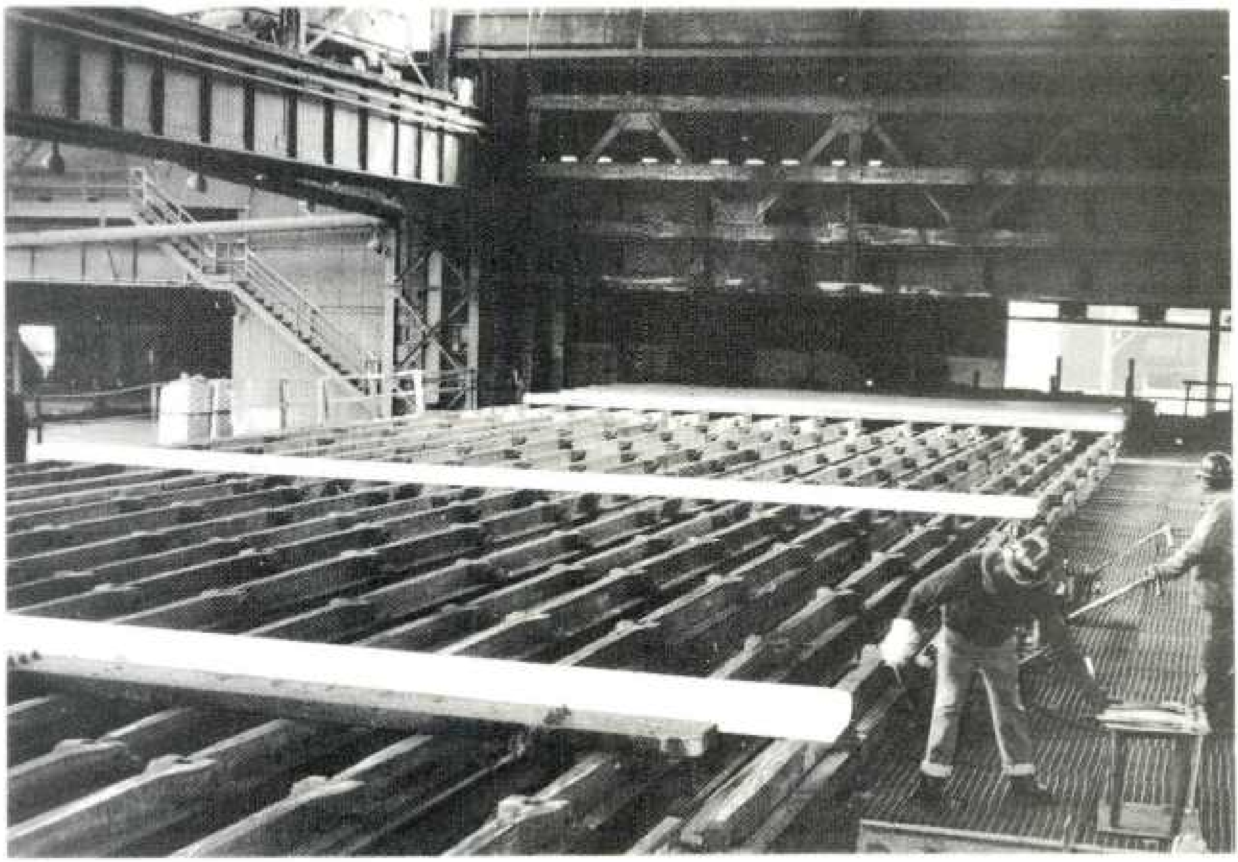


Figure B21. 21 inch Cooling Bed Which Air Cools Billets Prior to Final Slow Cool in Either Bung Furnace or Cooling Boxes

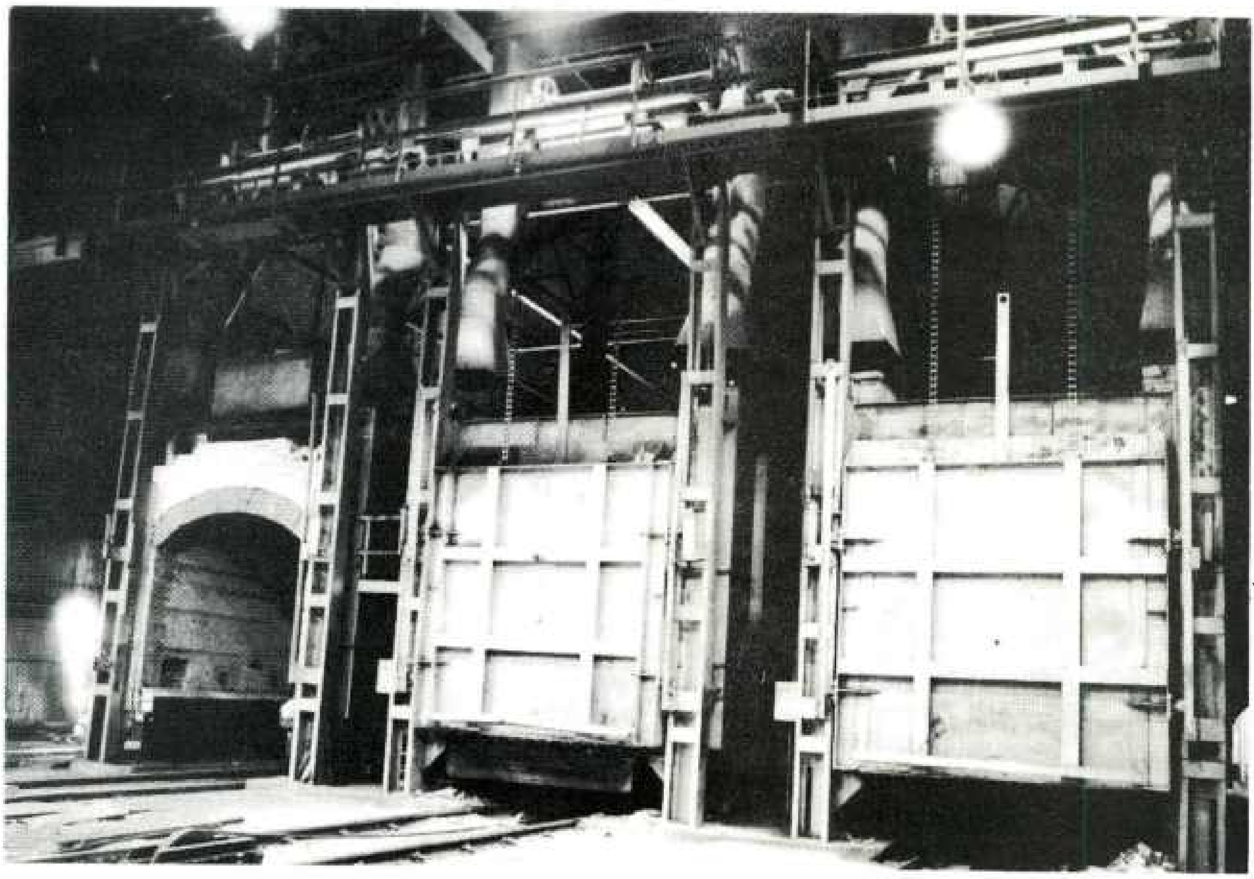


Figure B22. Bethlehem's Bung Furnace

Figure B23. Typical Cooling Boxes

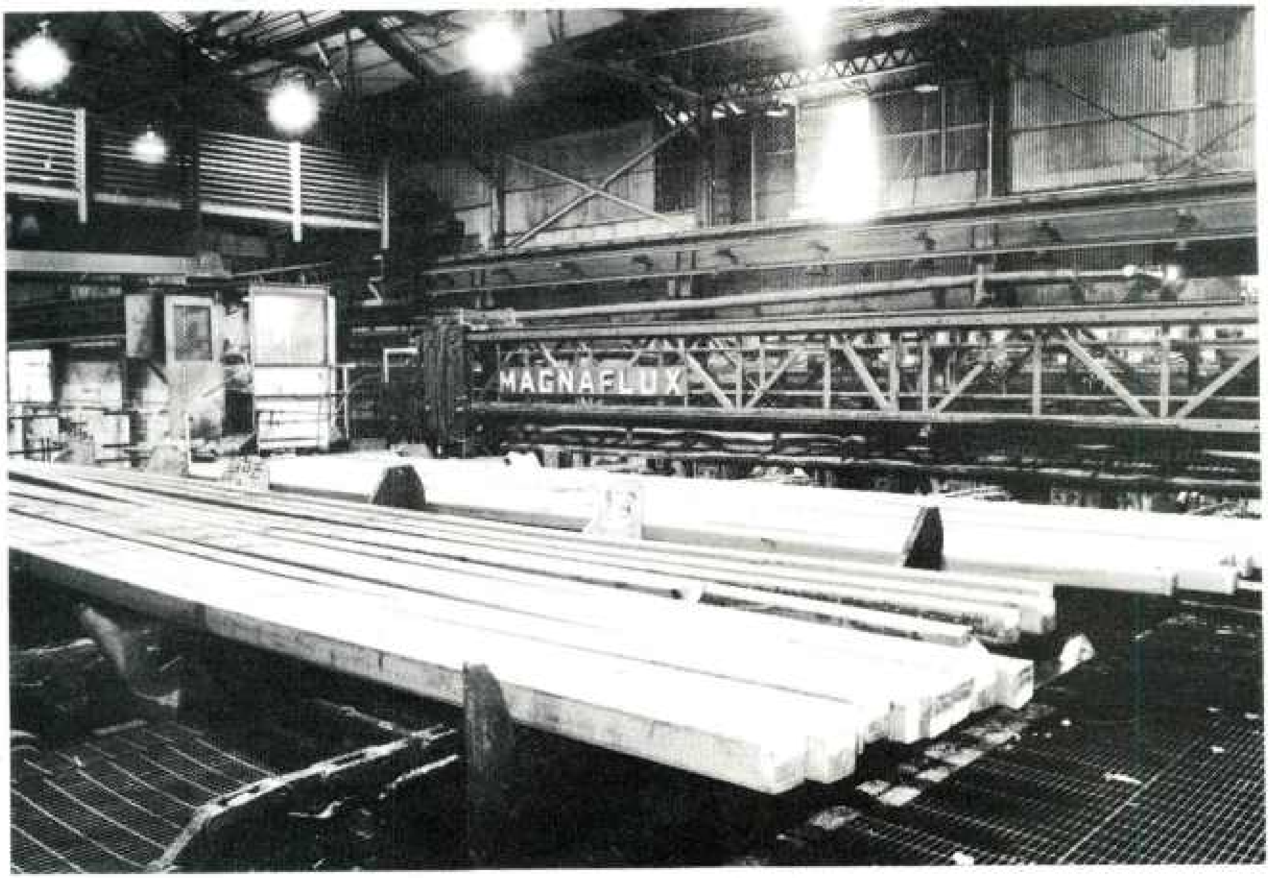


Figure B24. Bethlehem's Billet Magnaflux Operation

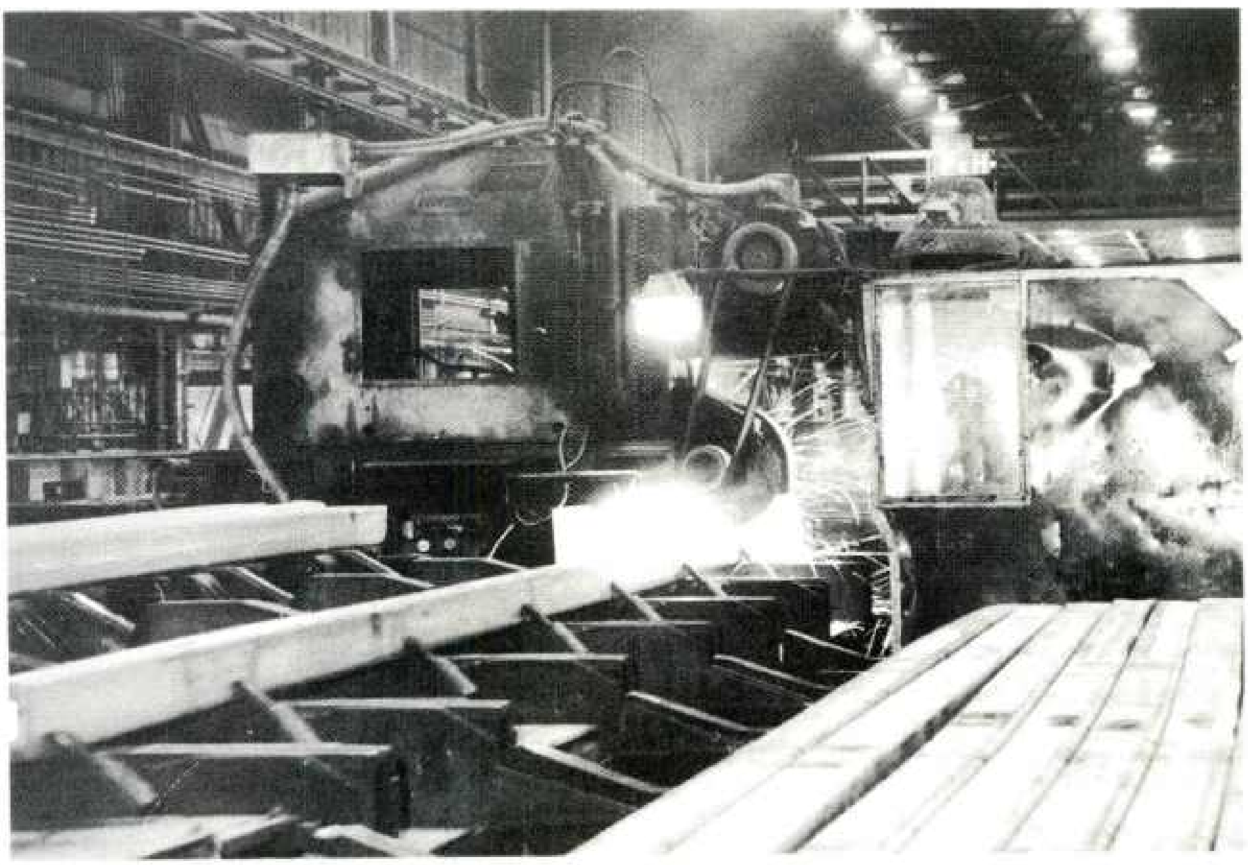


Figure B25. Bethlehem's Grinding Operation Which Removes Seams and Surface Defects Detected from the Magnaflux Operation

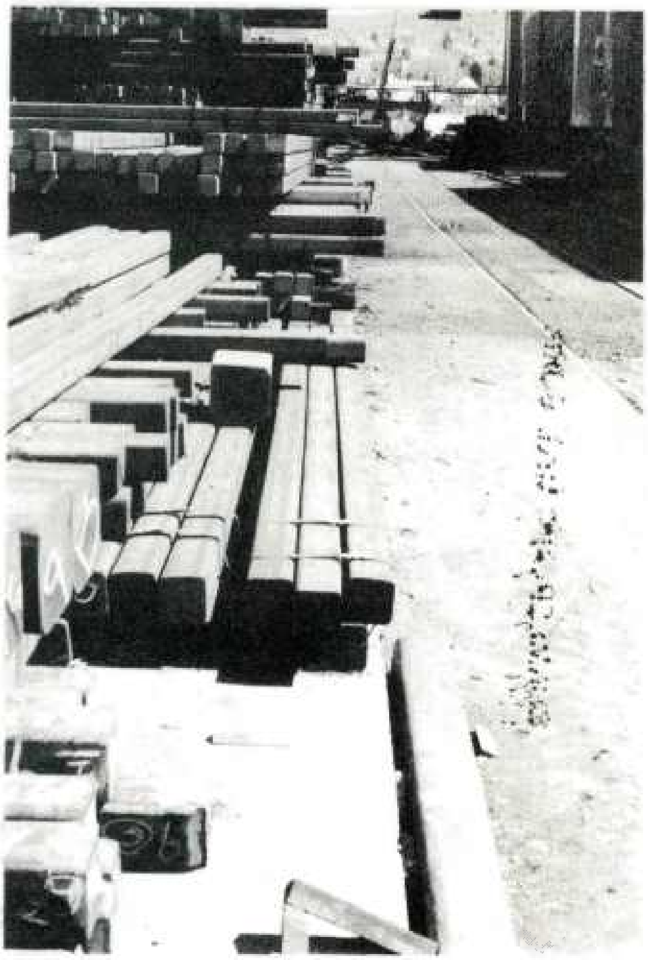


Figure B26. Republic Steel illustrating straight billets

Figure B27. Bethlehem Steel Billet.

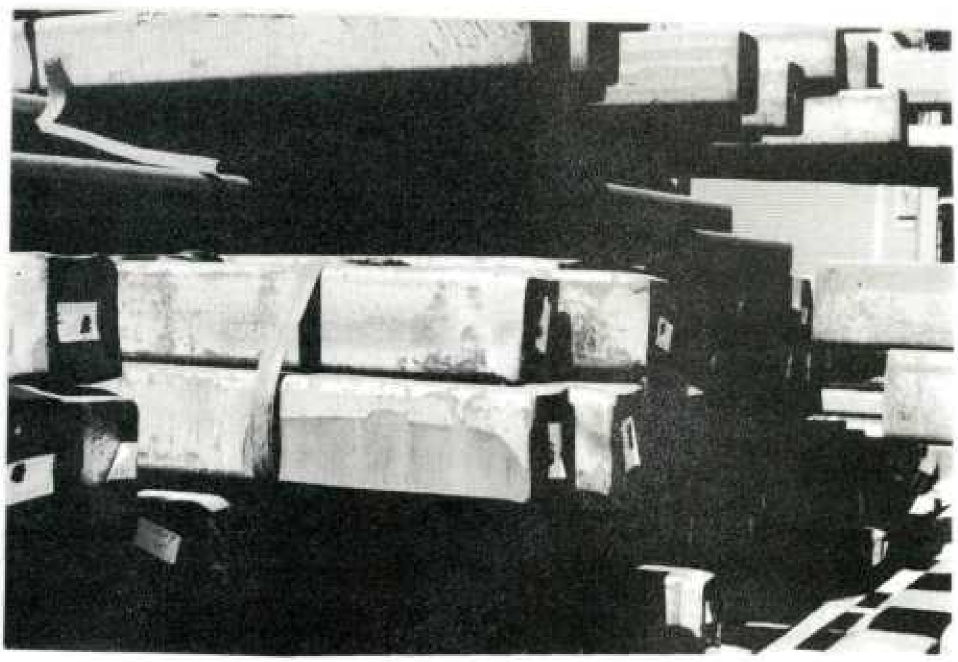


Figure B28. Illustration of Severe Grinding of Edge

Figure B29. Illustration of Hot-sawed Ends from Republic Steel

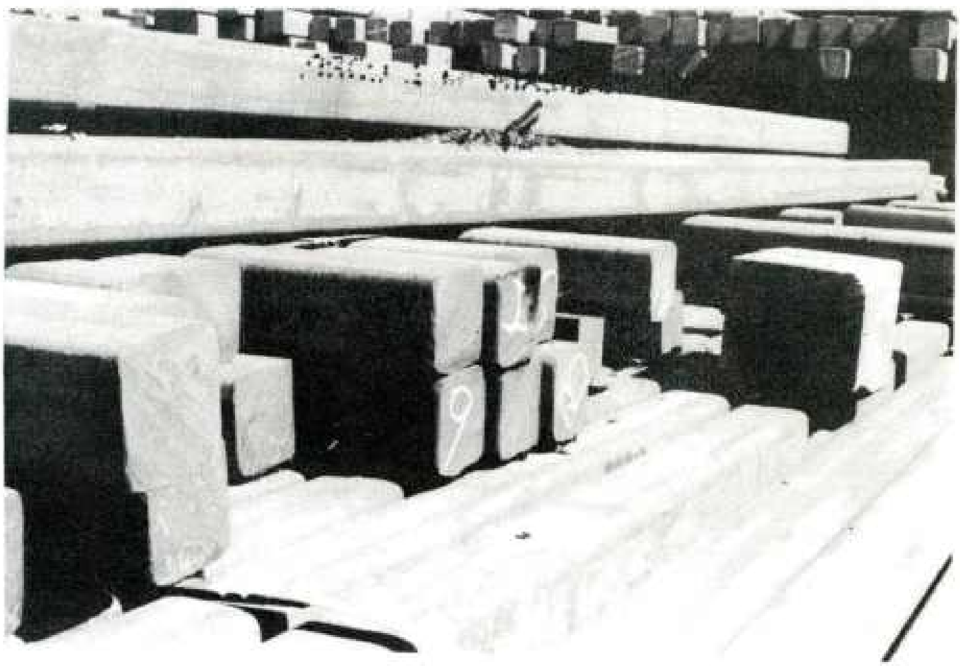


Figure B30. Another illustration of Republic Steel's Hot Sawed-Ends.

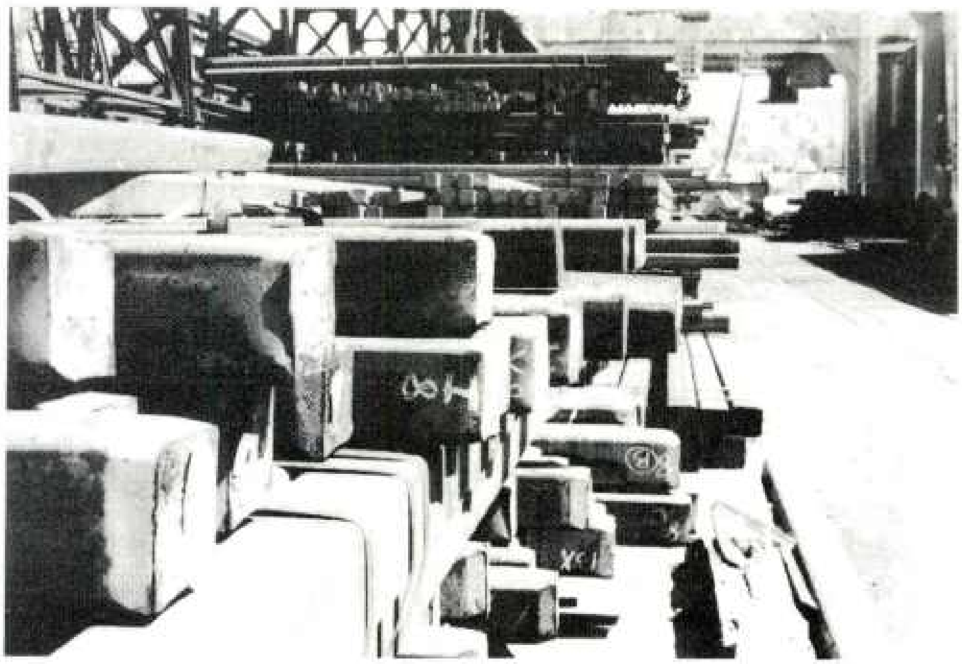


Figure B31. Illustration of Bethlehem's Hot Sheared Ends

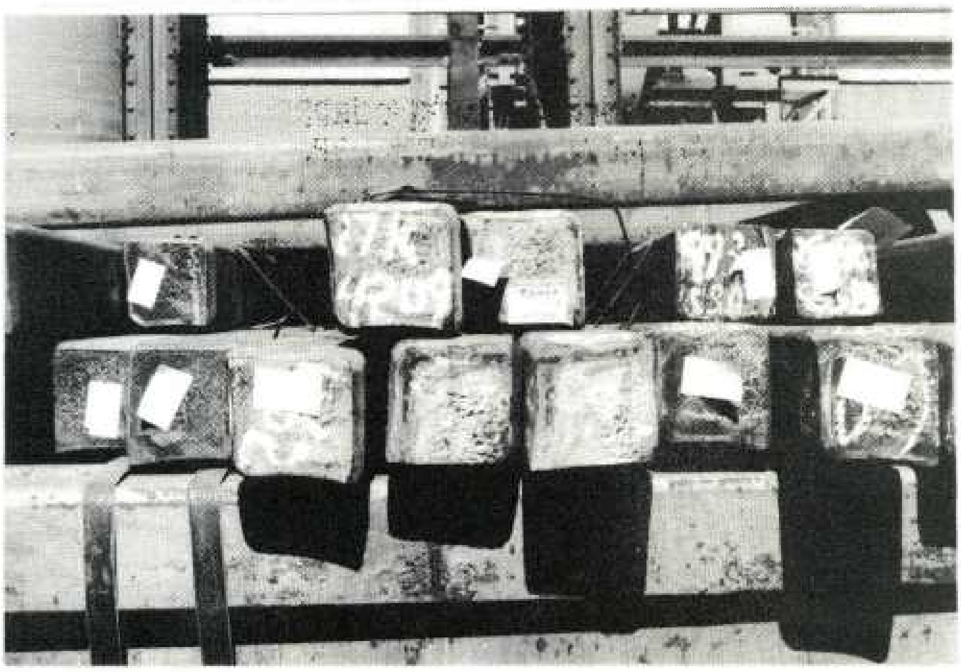
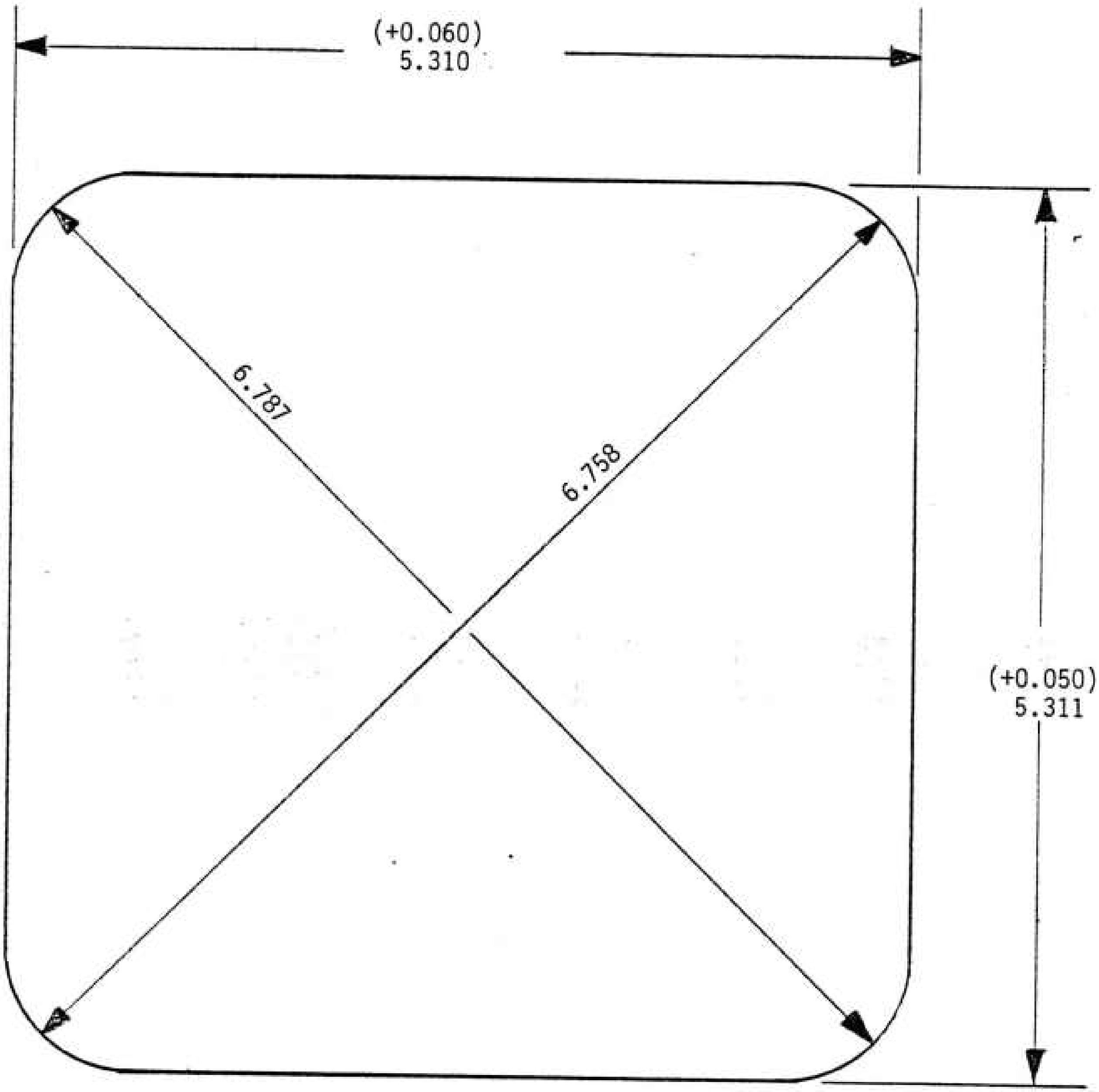


Figure B32. Illustration of Bethlehem's Hot Sheared Ends

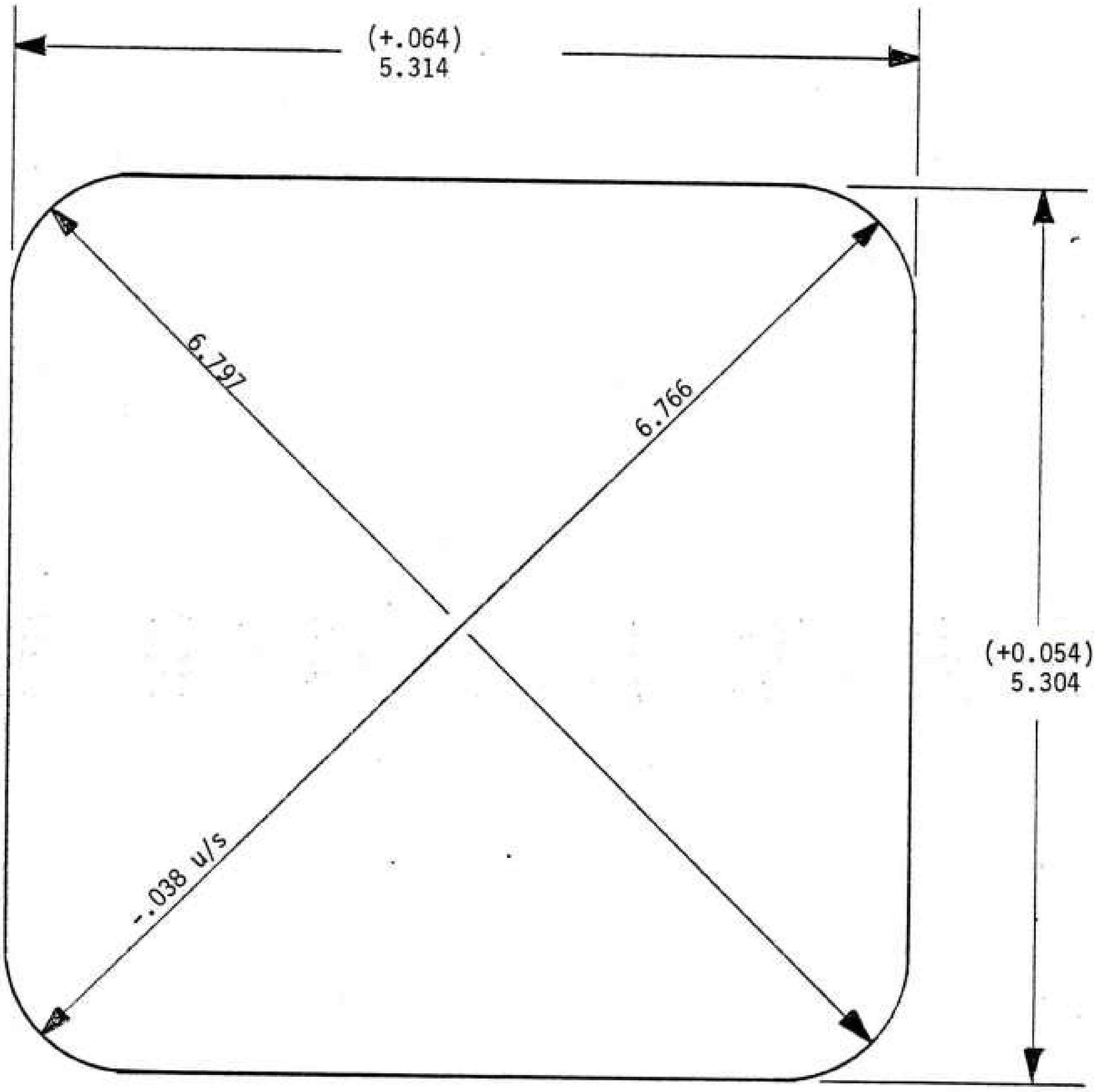
Appendix C

Dimension of Cross Section



Republic Steel

Figure C1. Billet 1AA.



Republic Steel

Figure C2. Billet 20BA.

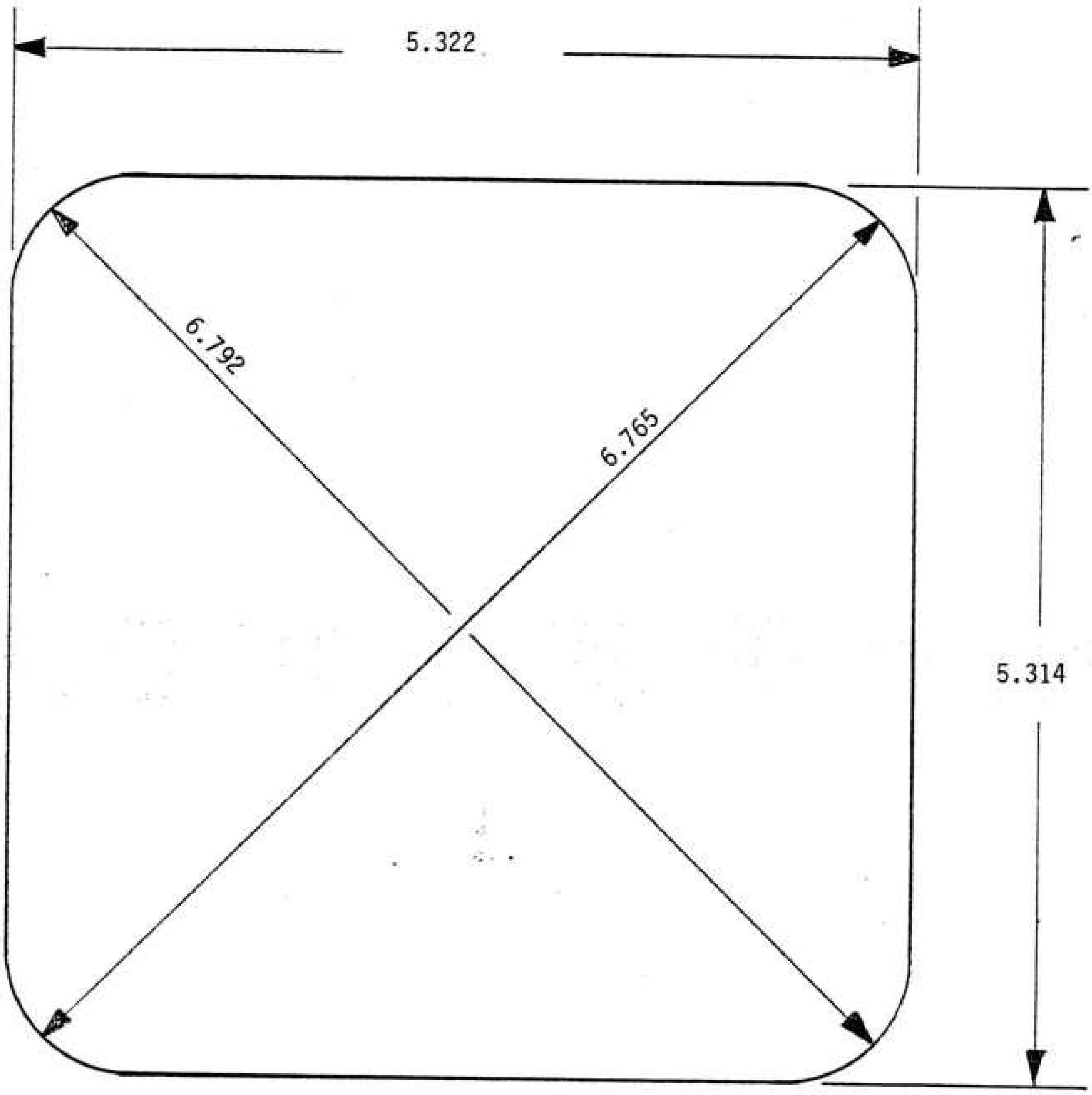
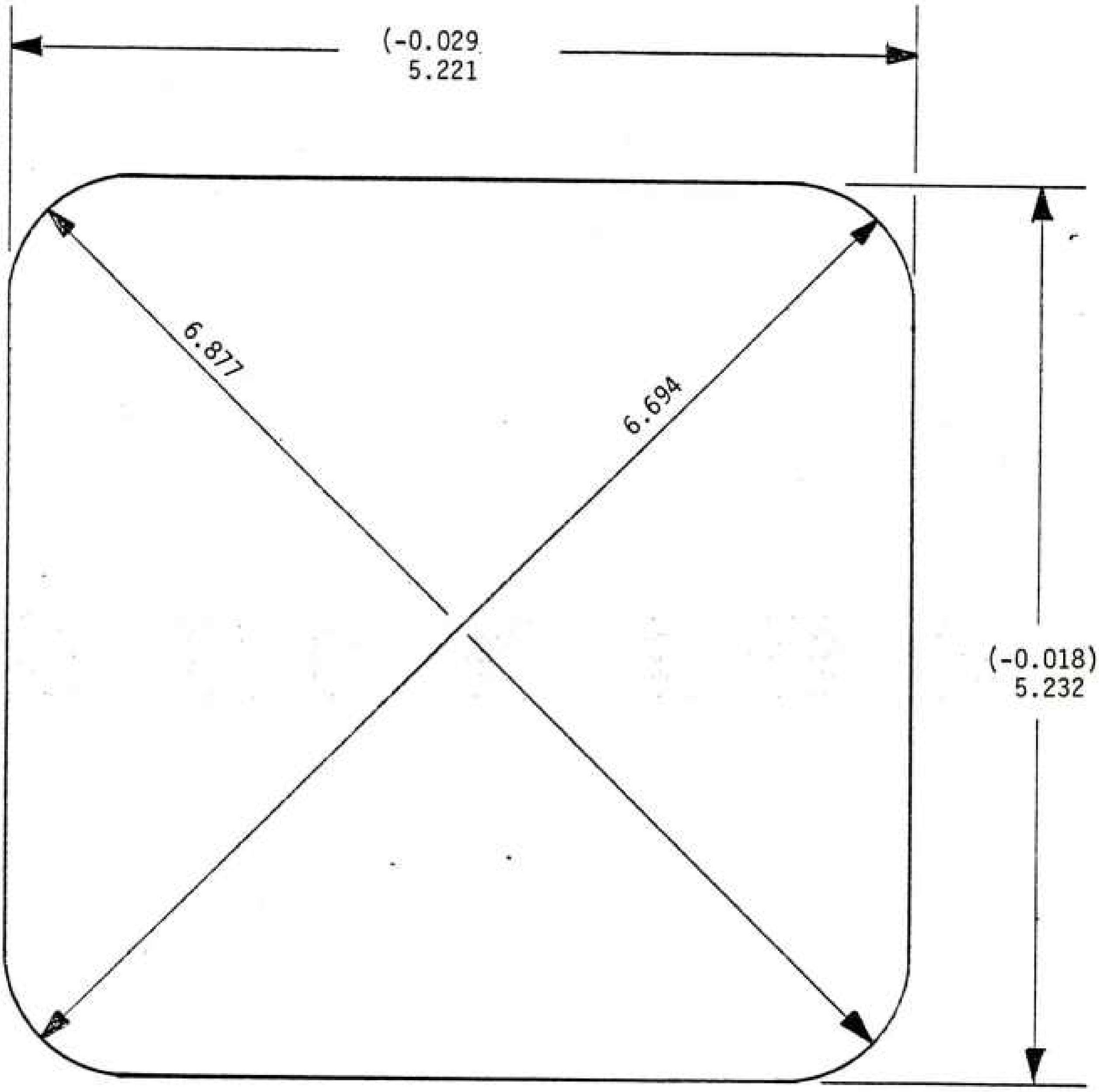
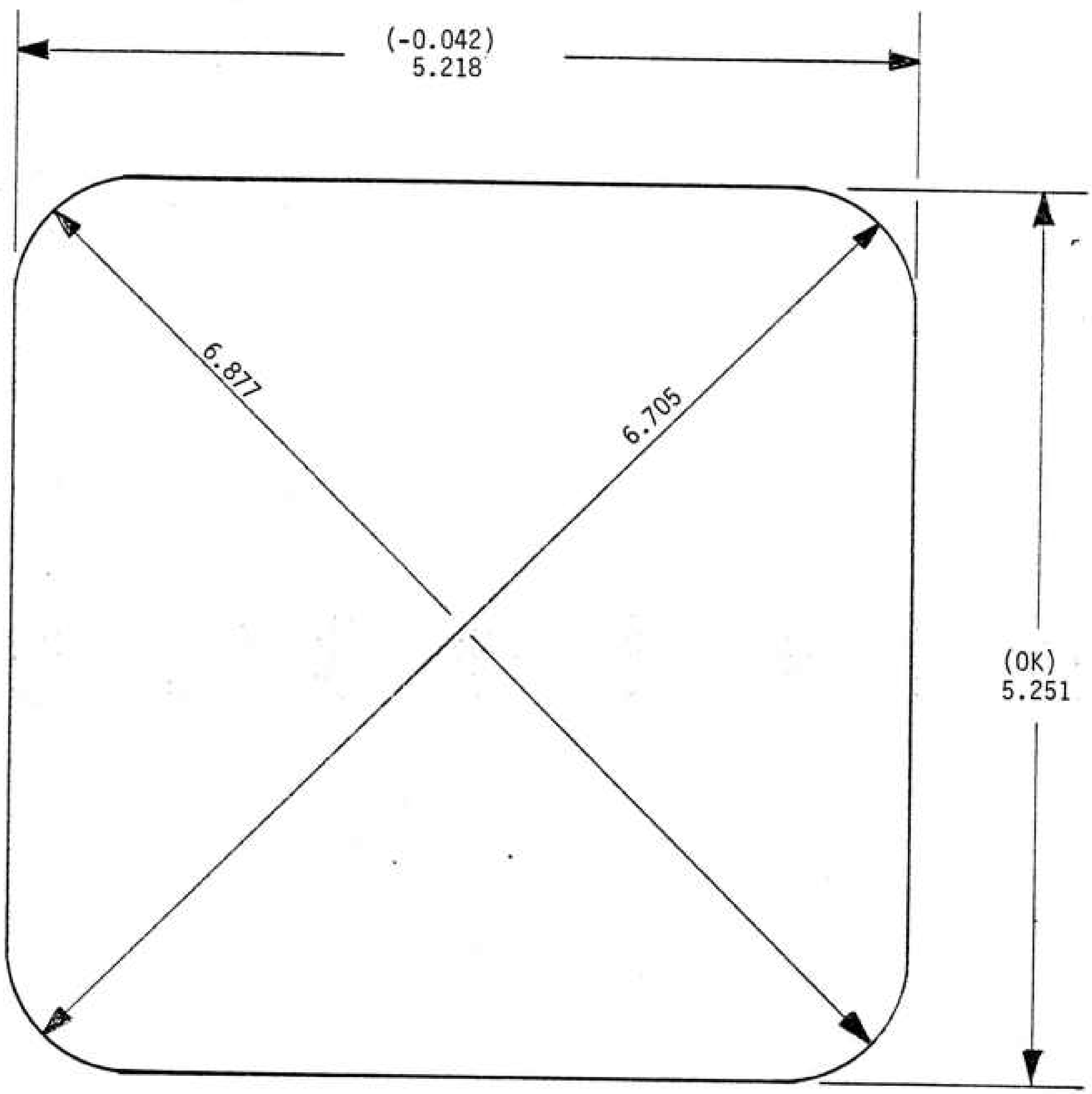


Figure C3. Billet 40BA.



Bethlehem Steel

Figure C4. Billet 11C.



Bethlehem Steel

Figure C5. Billet 20X.

5.250 x 5.250 = Cross Section

6.804 + .090 = Diagonal

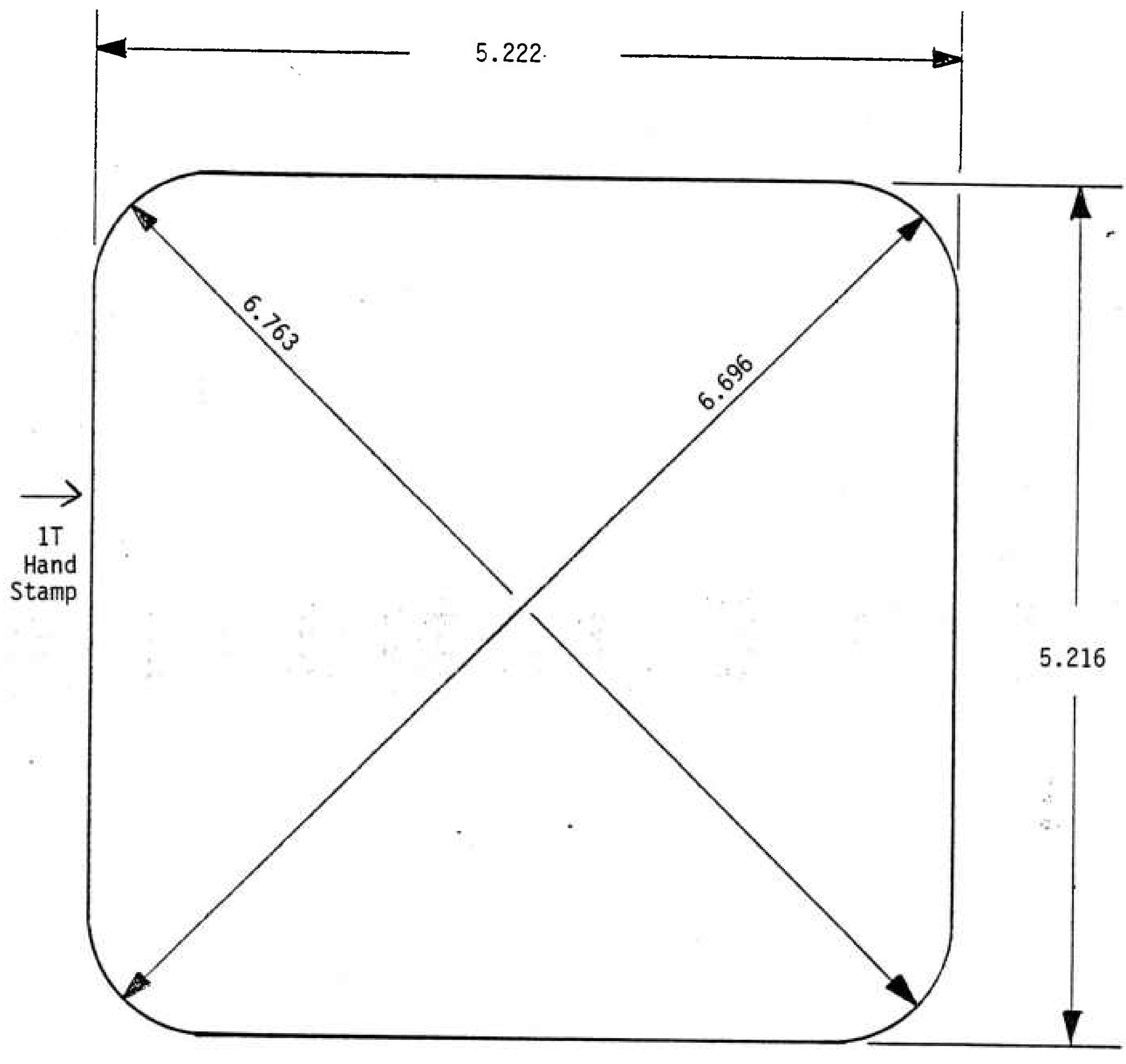


Figure C6. Billet 1T.

Appendix D

Photographs of Macro Cleanliness

Macro Cleanliness
Republic Steel

Figure D1. Billet 1AA.

Macro Cleanliness
Republic Steel

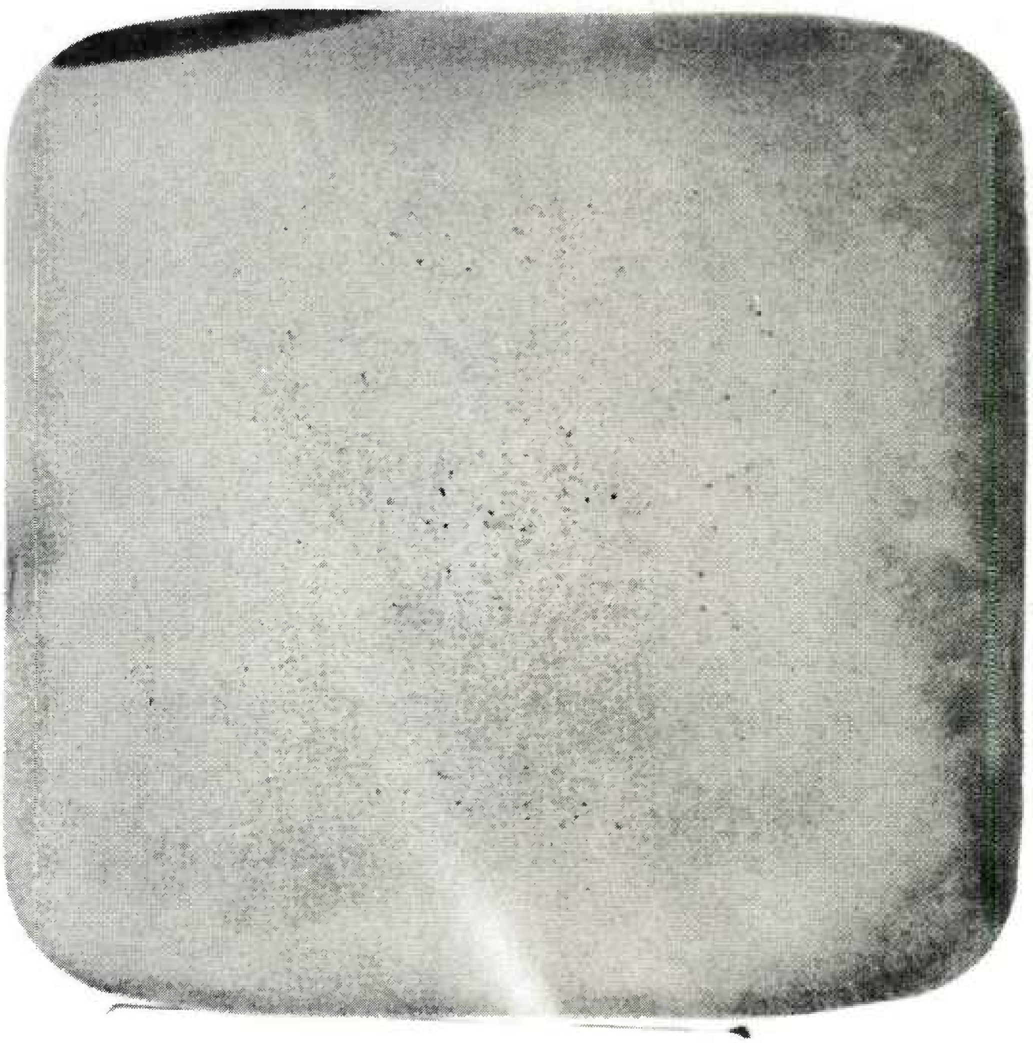


Figure D2. Billet 1BA.

Figure D3. Billet 1BD.

Macro Cleanliness
Republic Steel

Figure D4. Billet 20AA.

Macro Cleanliness
Republic Steel

Figure D5. Billet 20BA.

Macro Cleanliness
Republic Steel

Figure D6. Billet 20BD.

Macro Cleanliness
Republic Steel

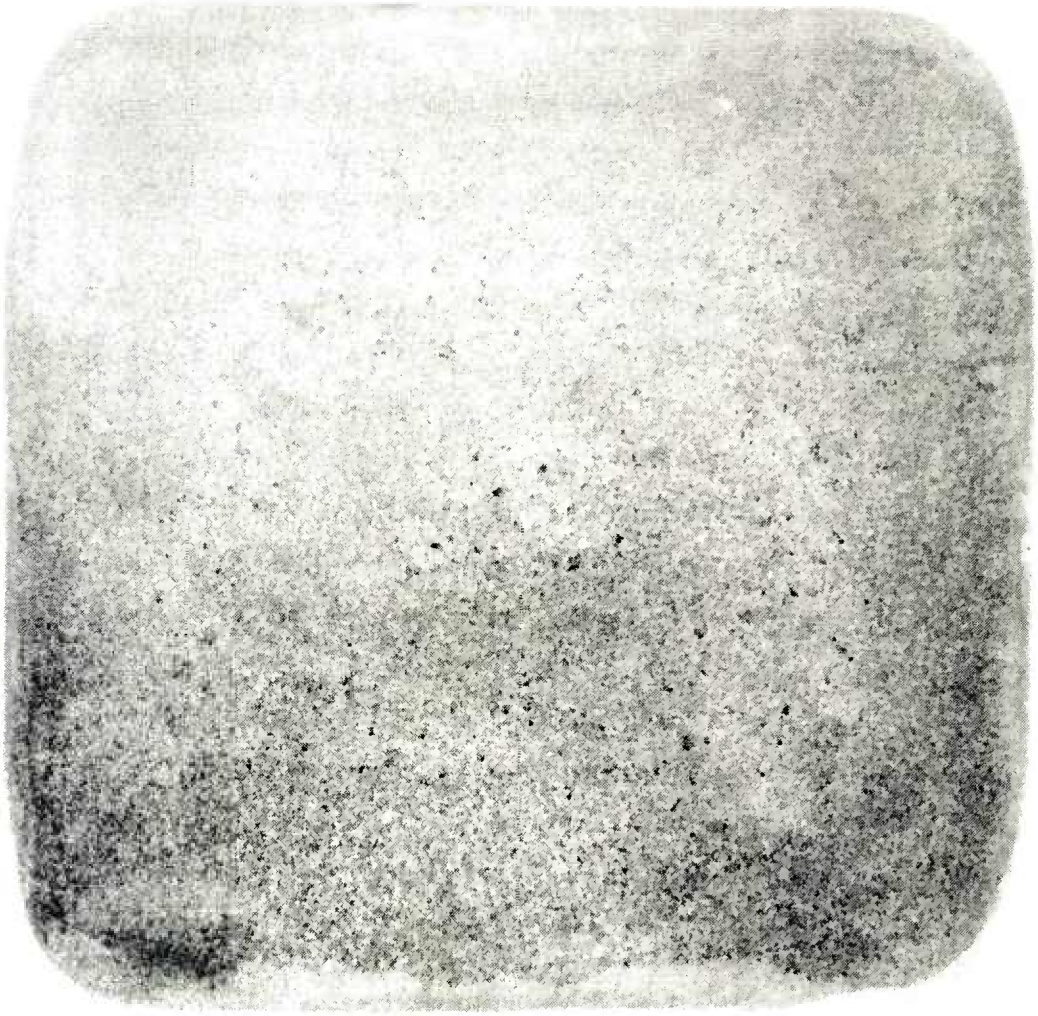


Figure D7. Billet 40AA.

Macro Cleanliness
Bethlehem Steel

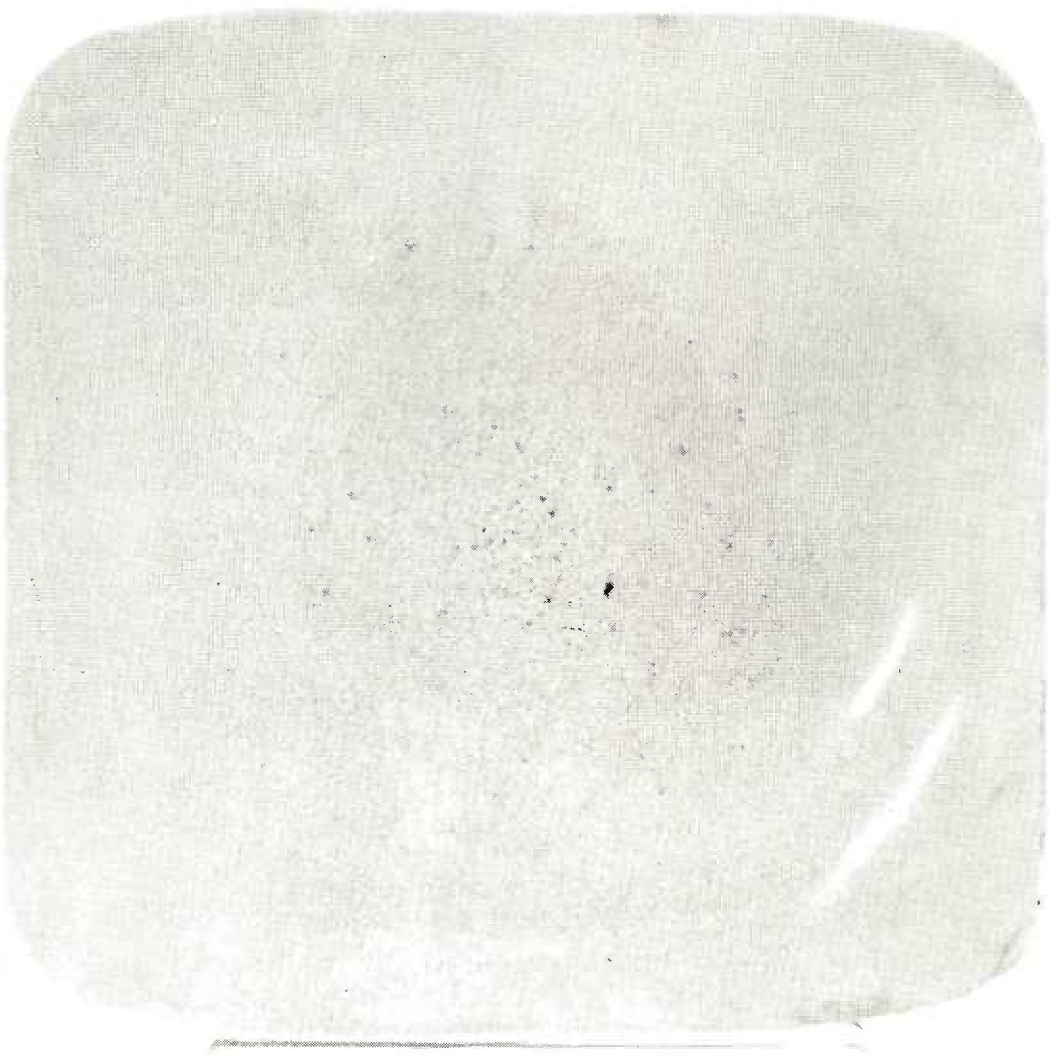


Figure D8. Billet 40BA.

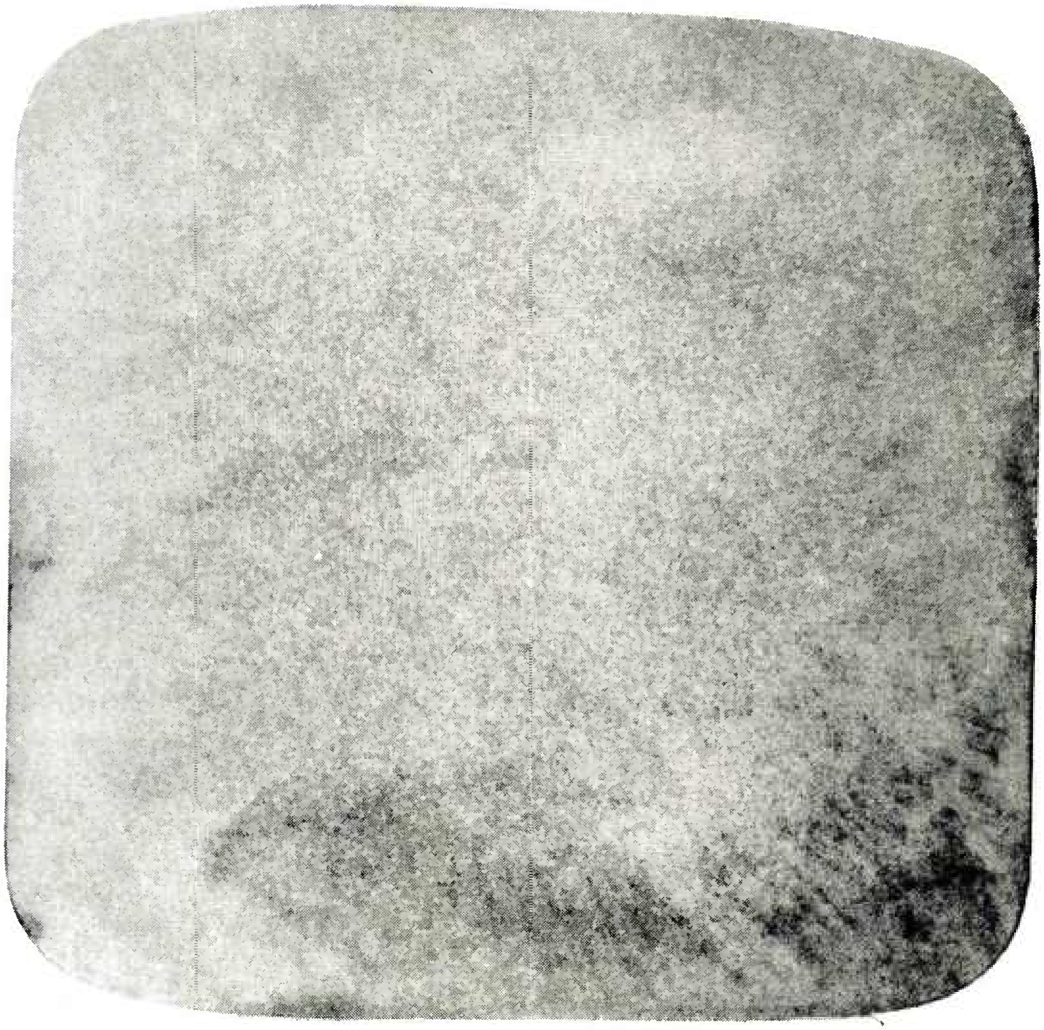


Figure D9. Billet 40BD.

Macro Cleanliness
Bethlehem Steel

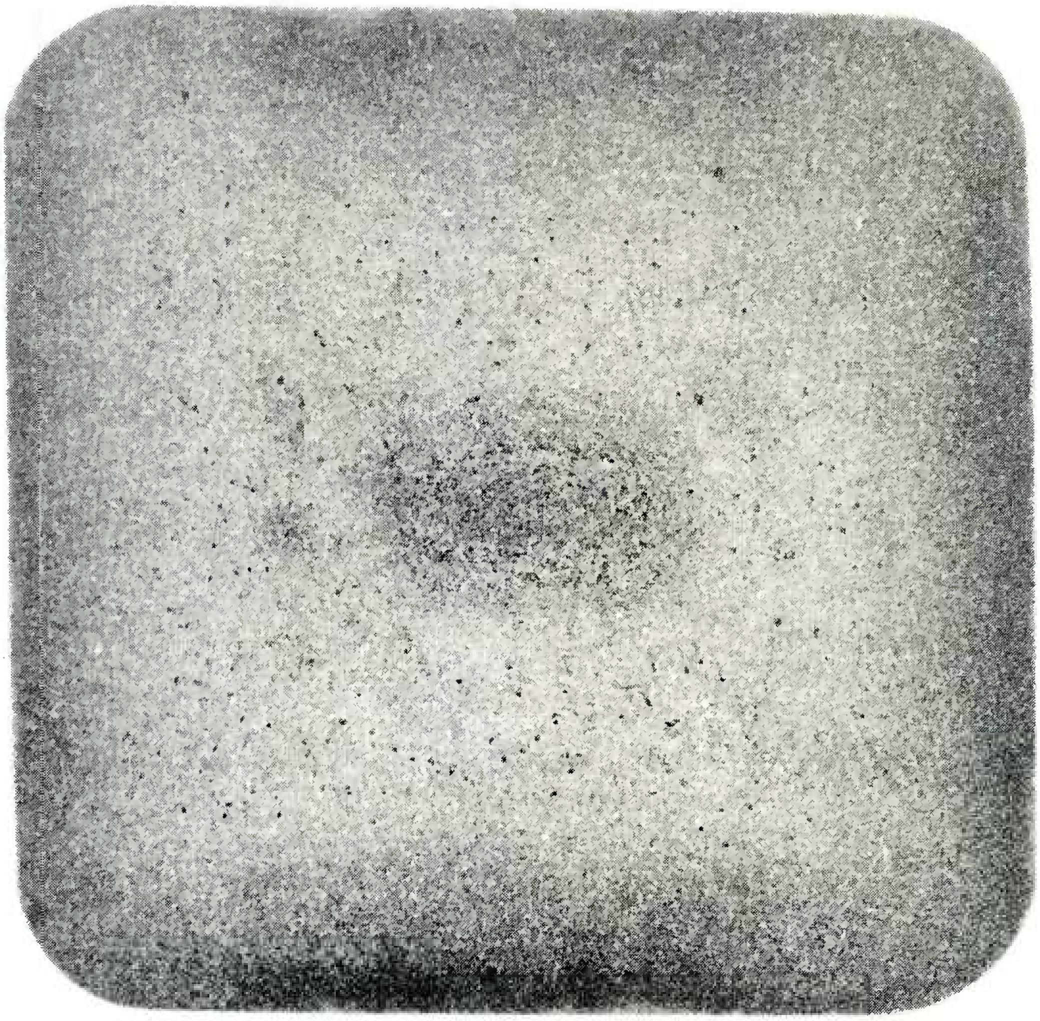


Figure D10. Billet 1T.

Macro Cleanliness
Bethlehem Steel

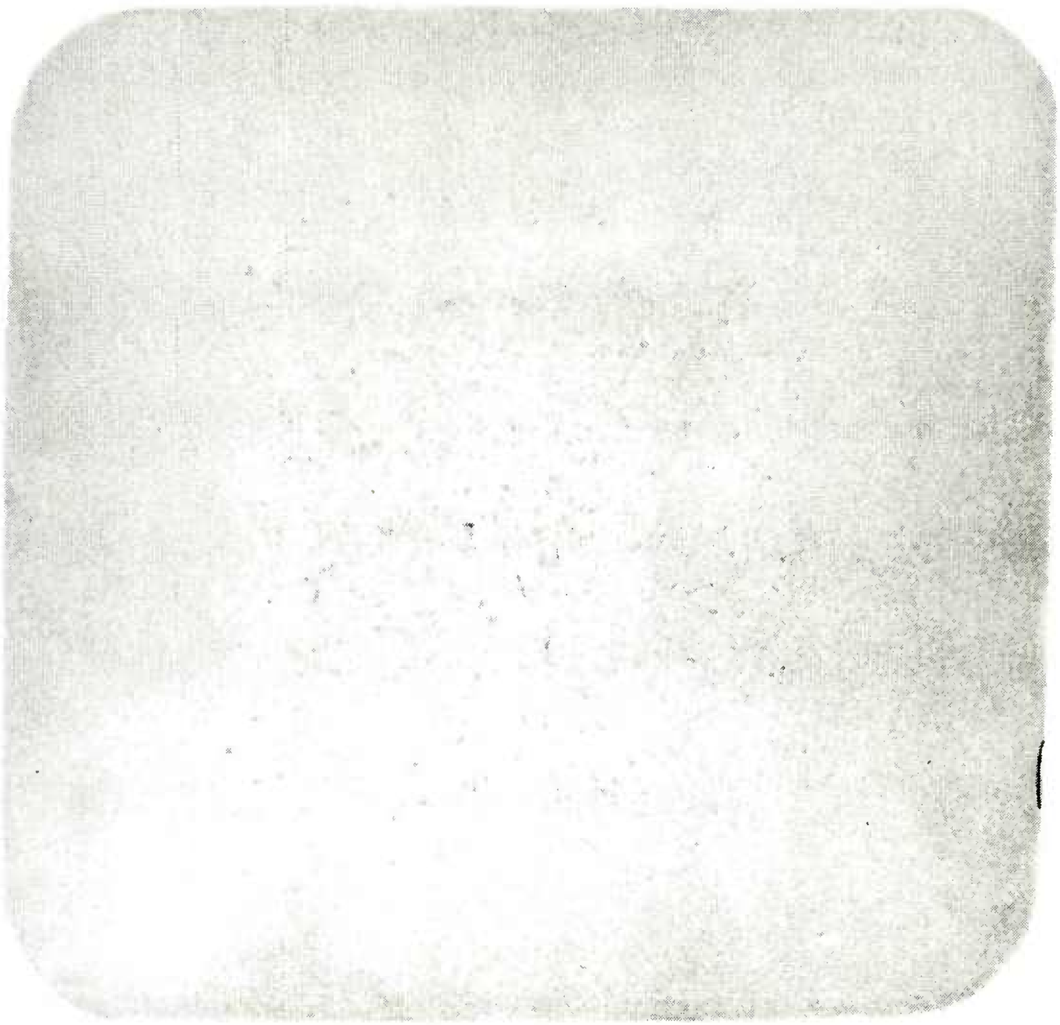


Figure D11. Billet 1C.

Macro Cleanliness
Bethlehem Steel

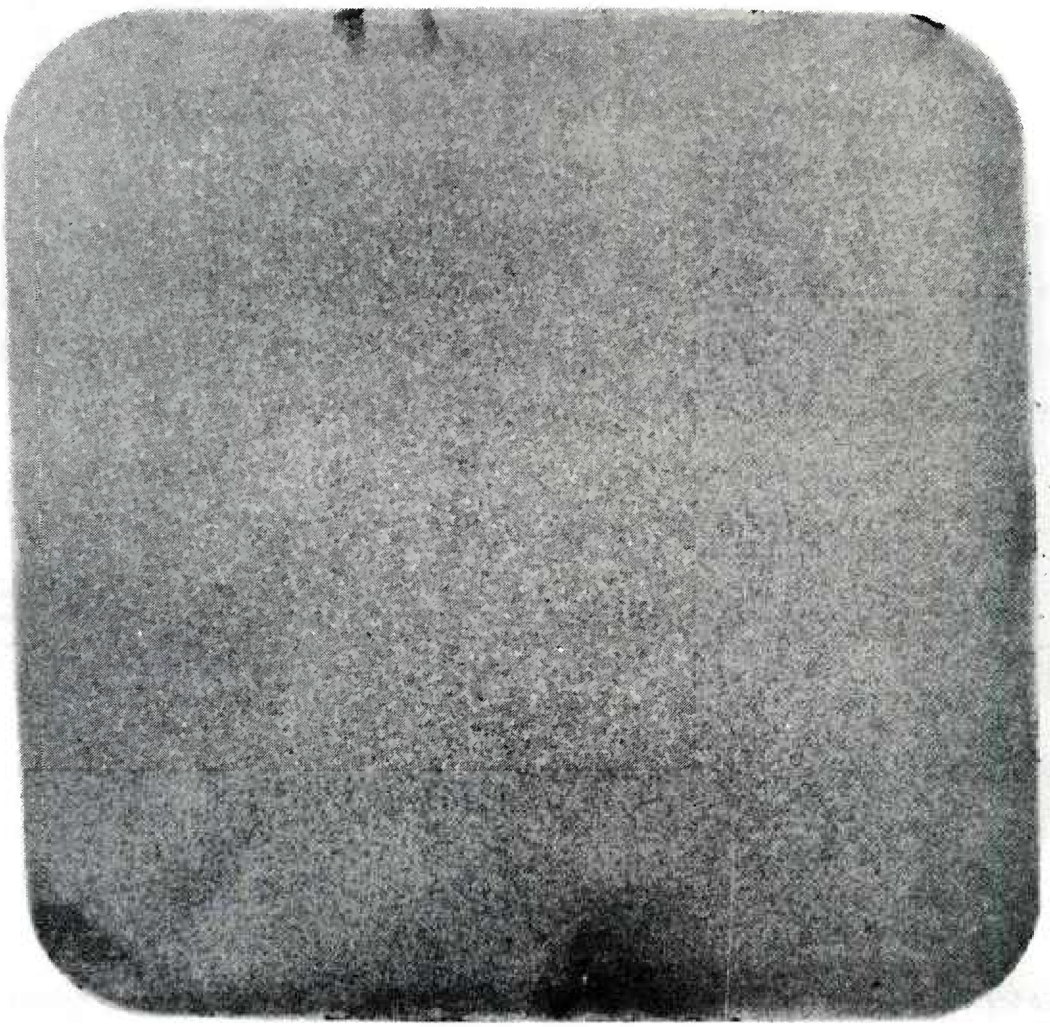


Figure D12. Billet 1X.

Macro Cleanliness
Bethlehem Steel

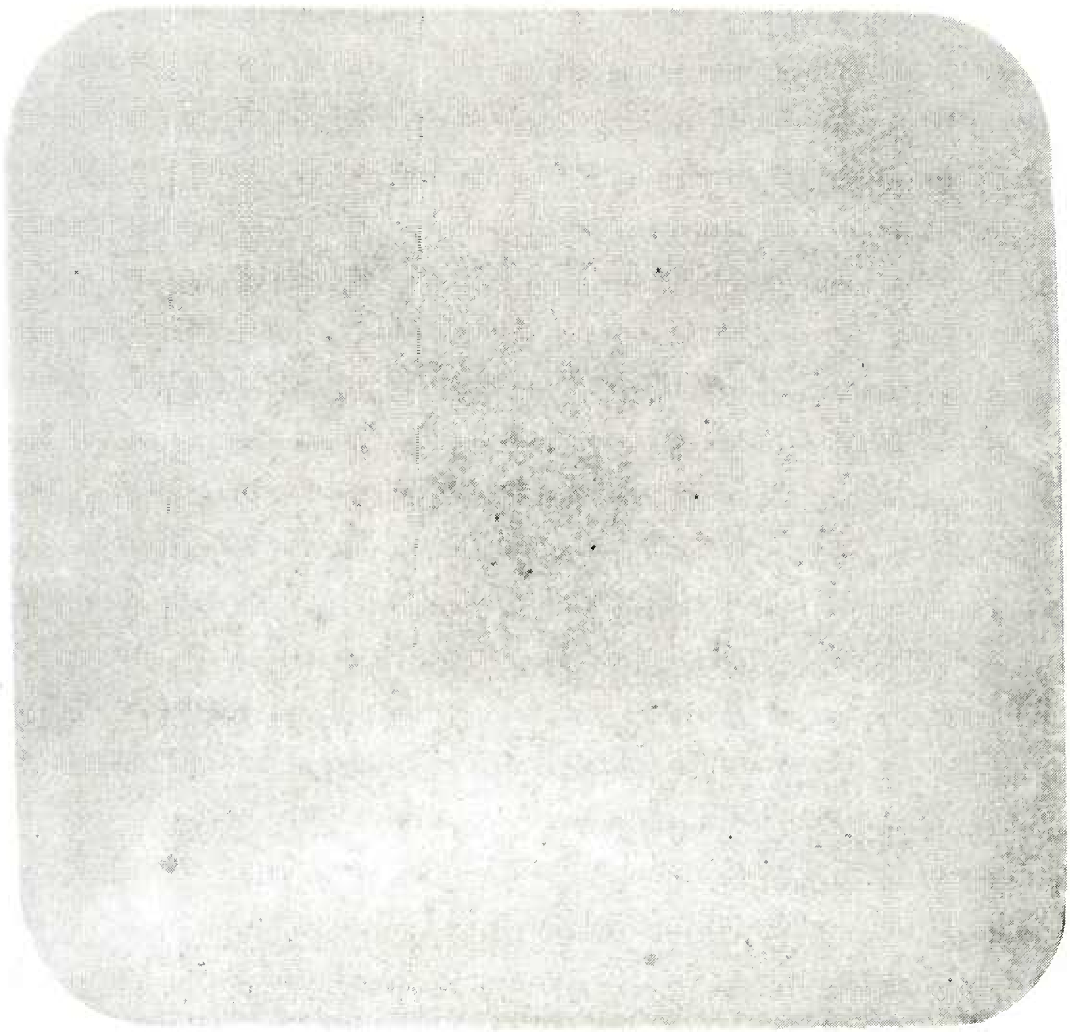


Figure D13. Billet 2T.

Macro Cleanliness
Bethlehem Steel

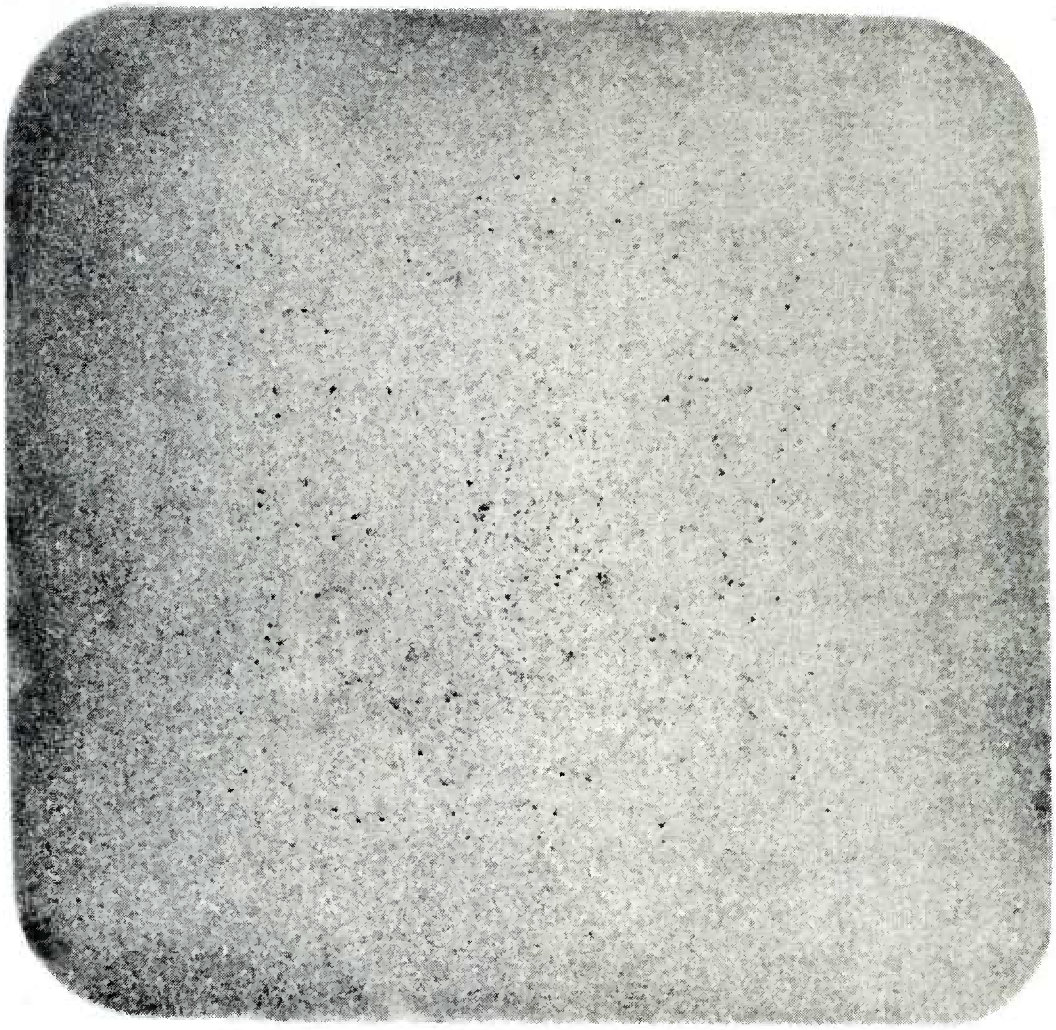


Figure D14. Billet 2C

Macro Cleanliness
Bethelhem Steel

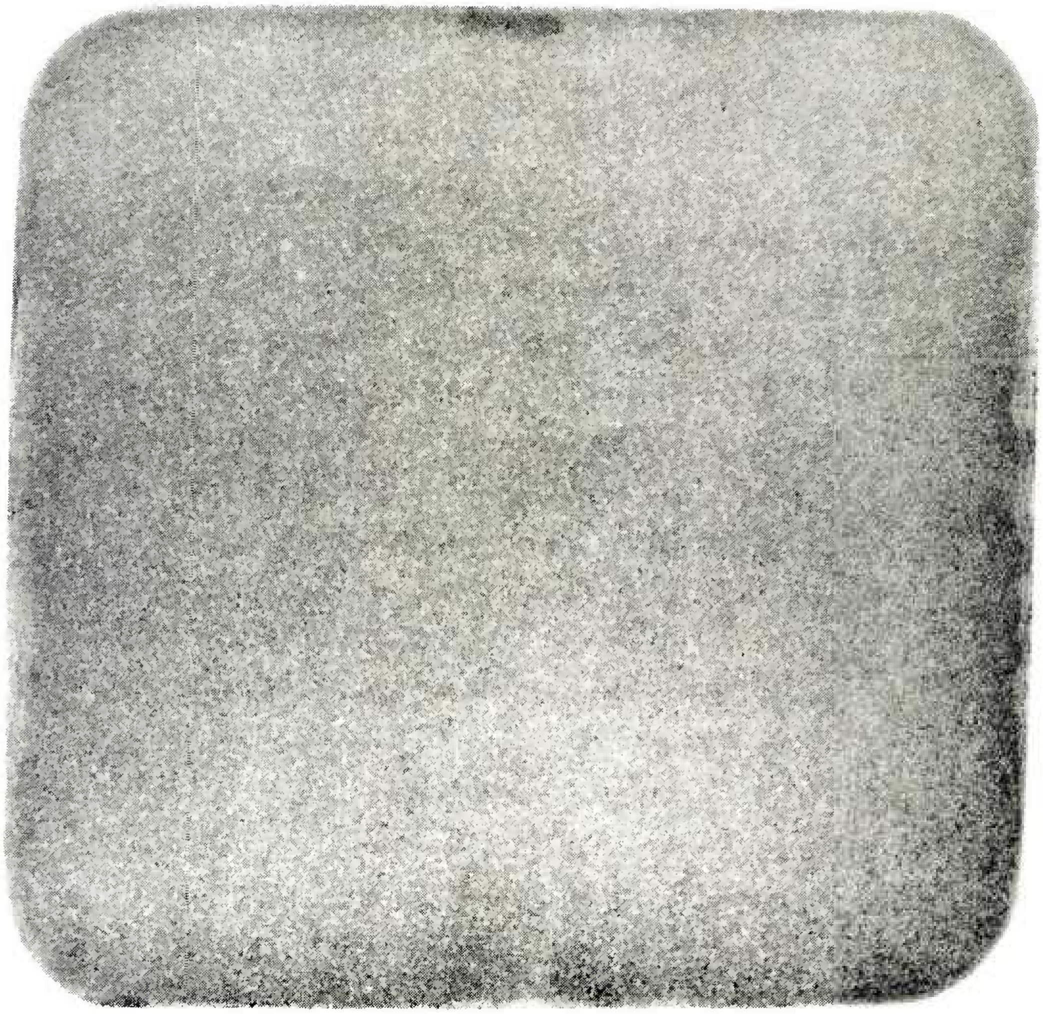


Figure D15. Billet 2X

Macro Cleanliness
Bethlehem Steel

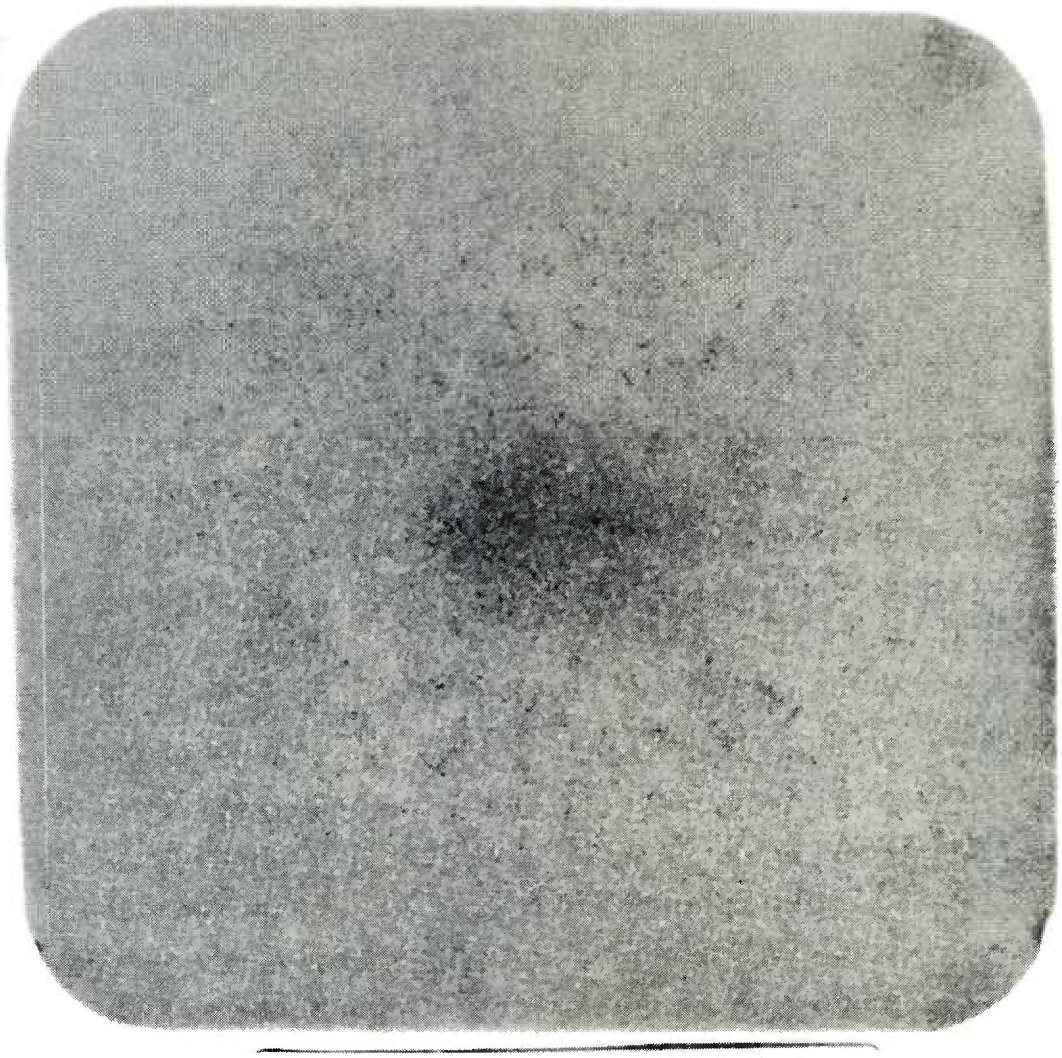


Figure D16. Billet 10T

Macro Cleanliness
Bethlehem Steel

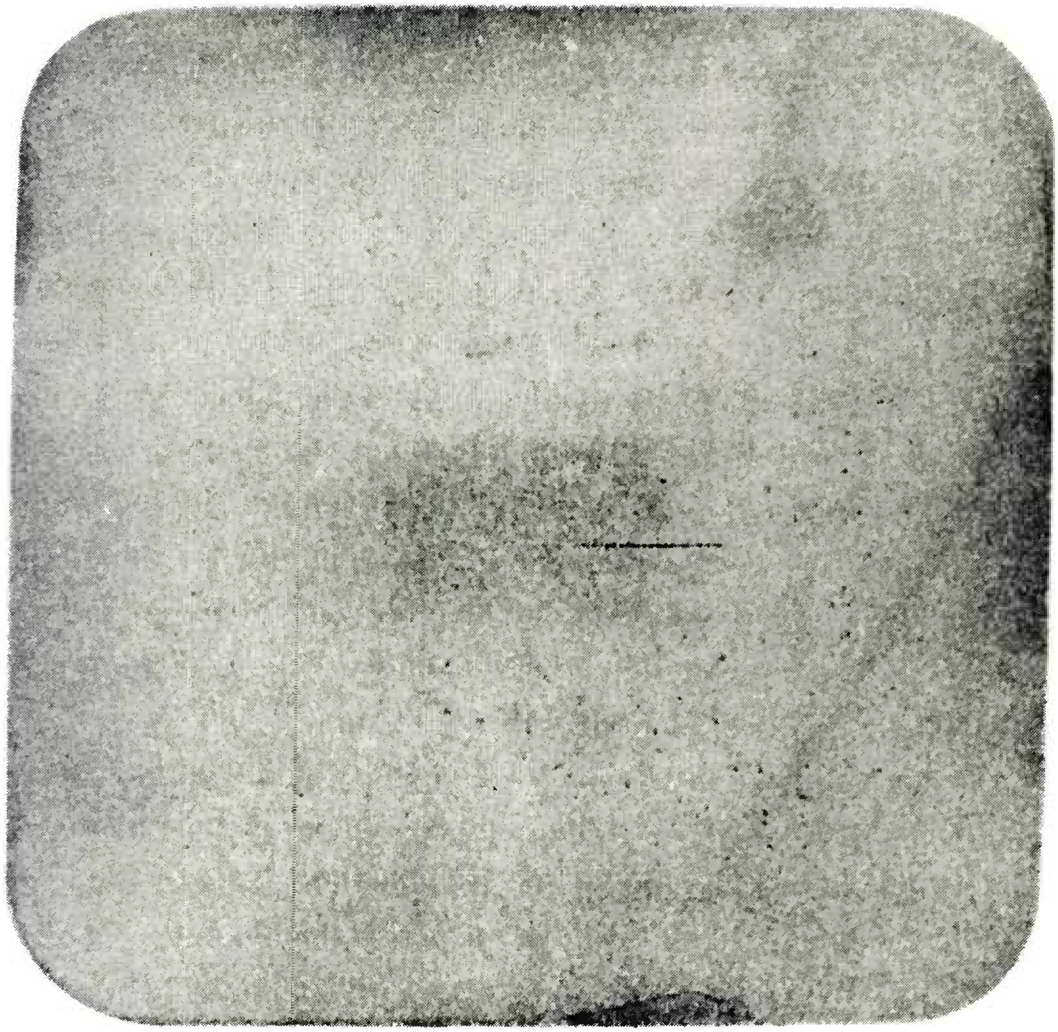


Figure D17. Billet 10C.

Macro Cleanliness
Bethlehem Steel

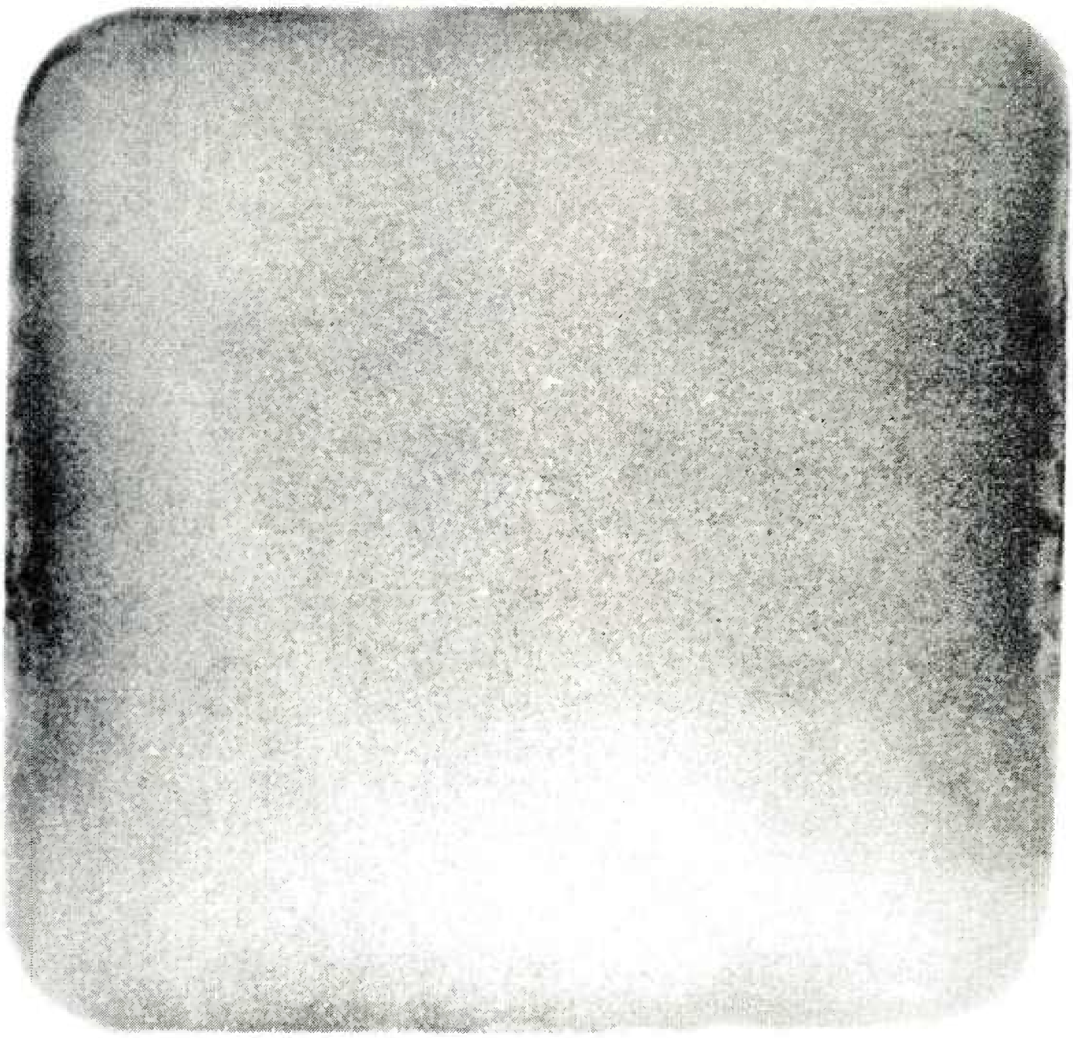


Figure D18. Billet 10X.

Macro Cleanliness
Bethlehem Steel

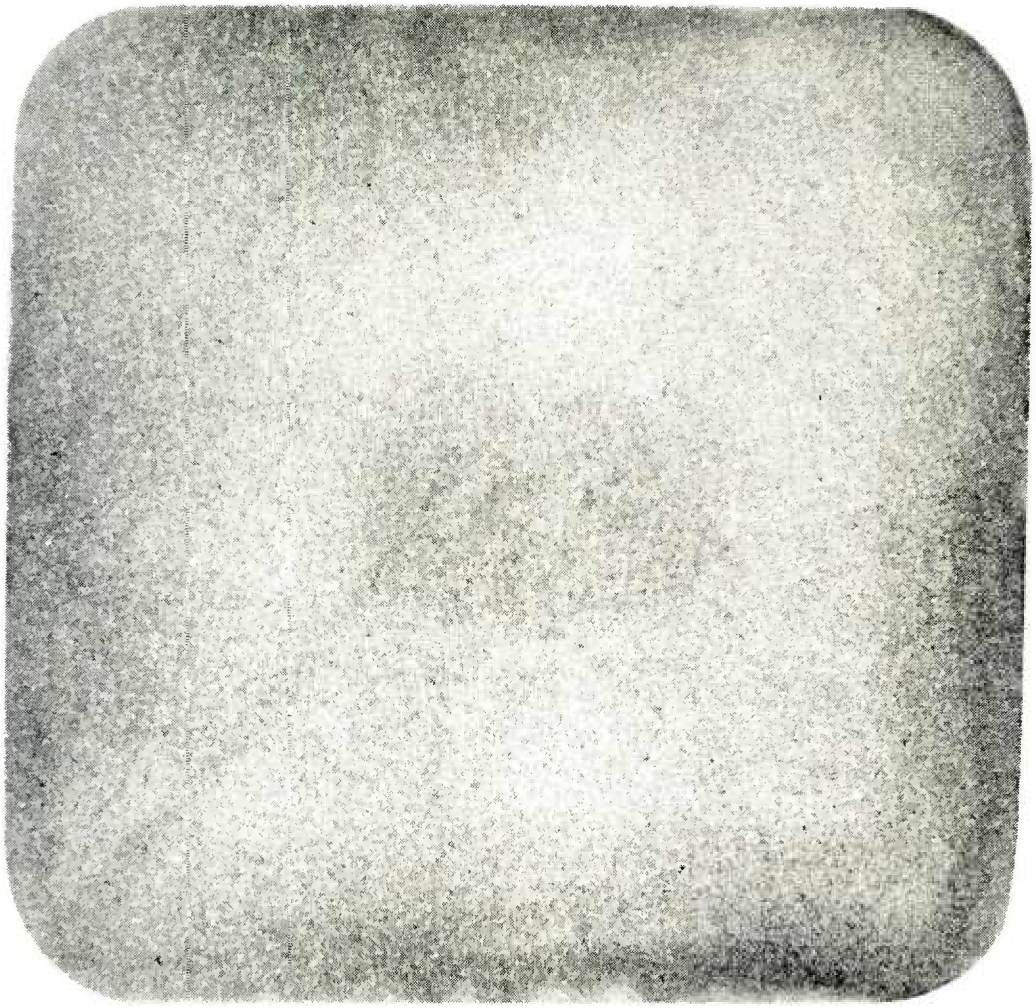


Figure D19. Billet 11T.

Macro Cleanliness
Bethlehem Steel

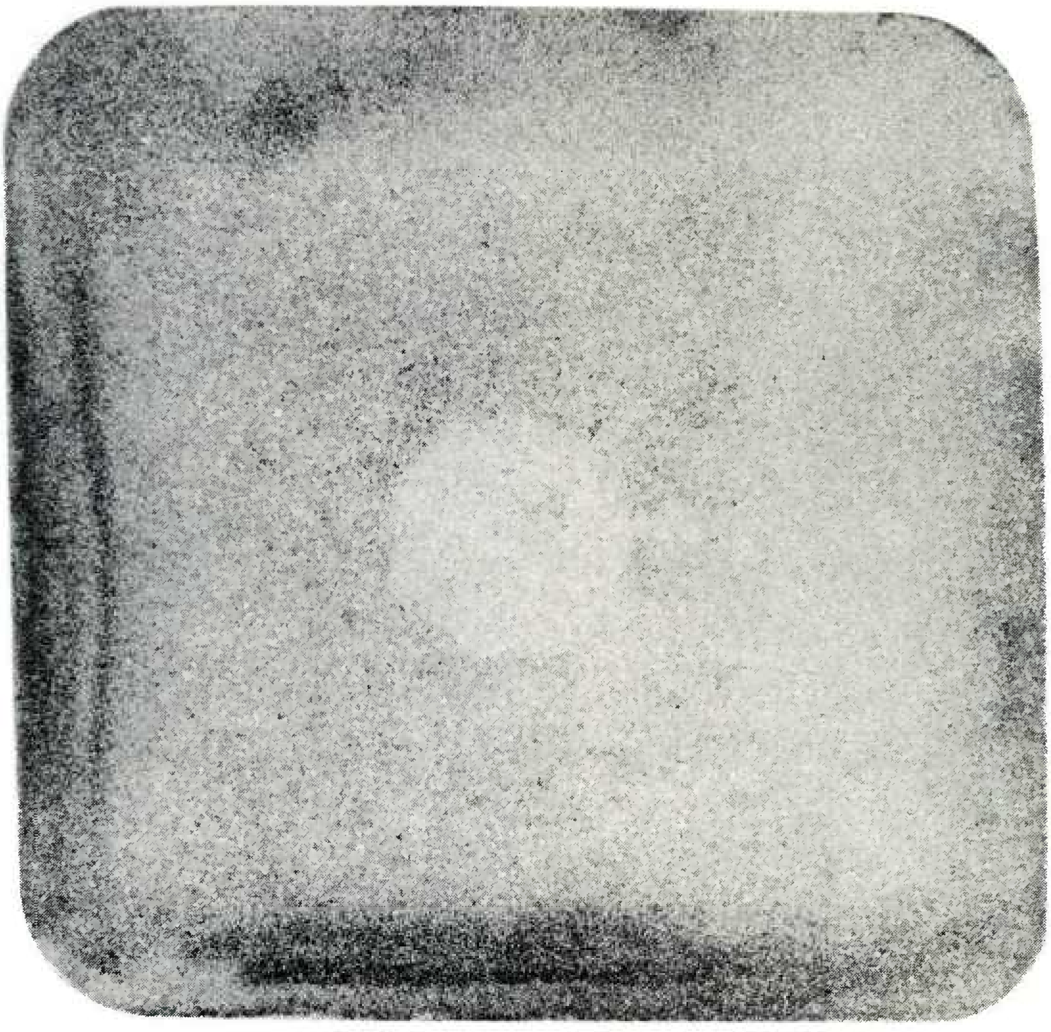


Figure D20. Billet 11C.

Macro Cleanliness
Bethlehem Steel

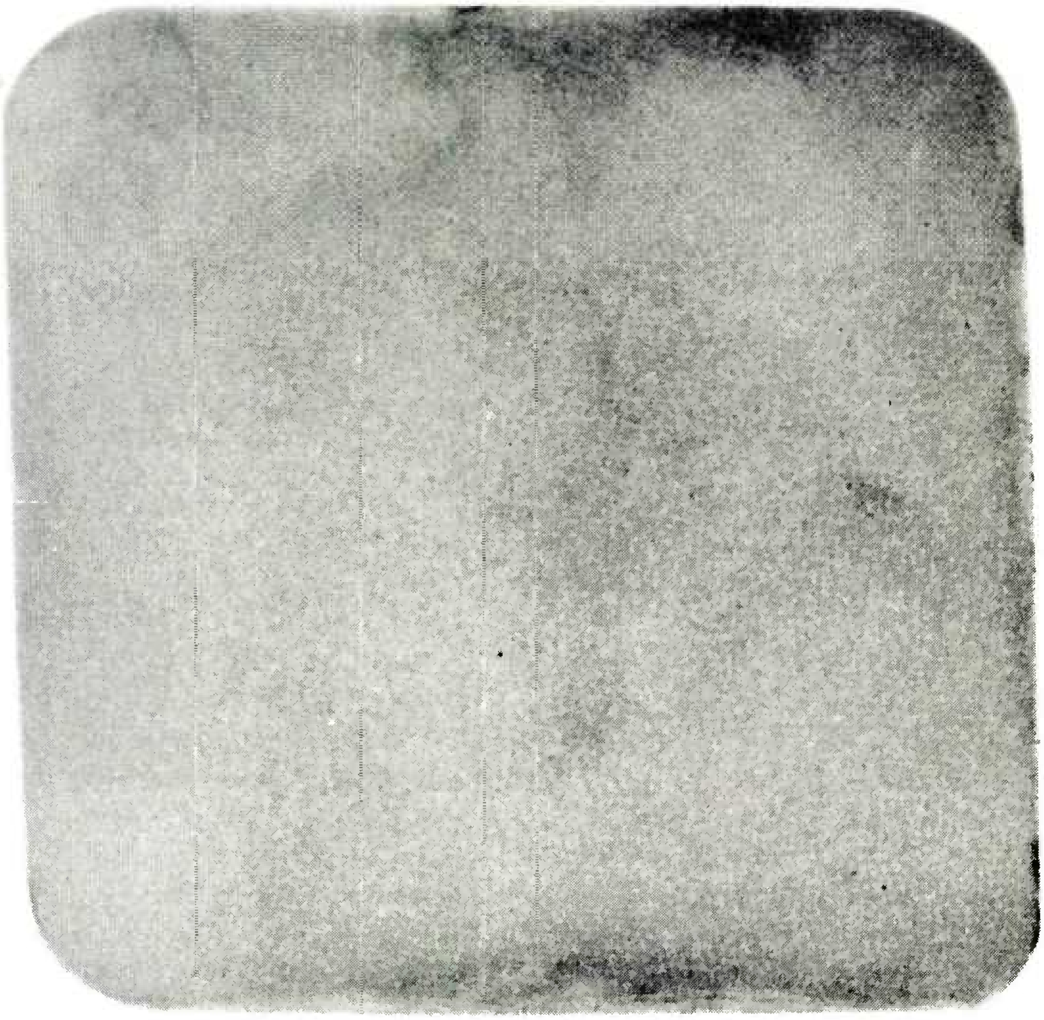


Figure D21. Billet 11X.

Macro Cleanliness
Bethlehem Steel

Figure D22. Billet 19T.

Figure D23. Billet 19C.

Macro Cleanliness
Bethlehem Steel

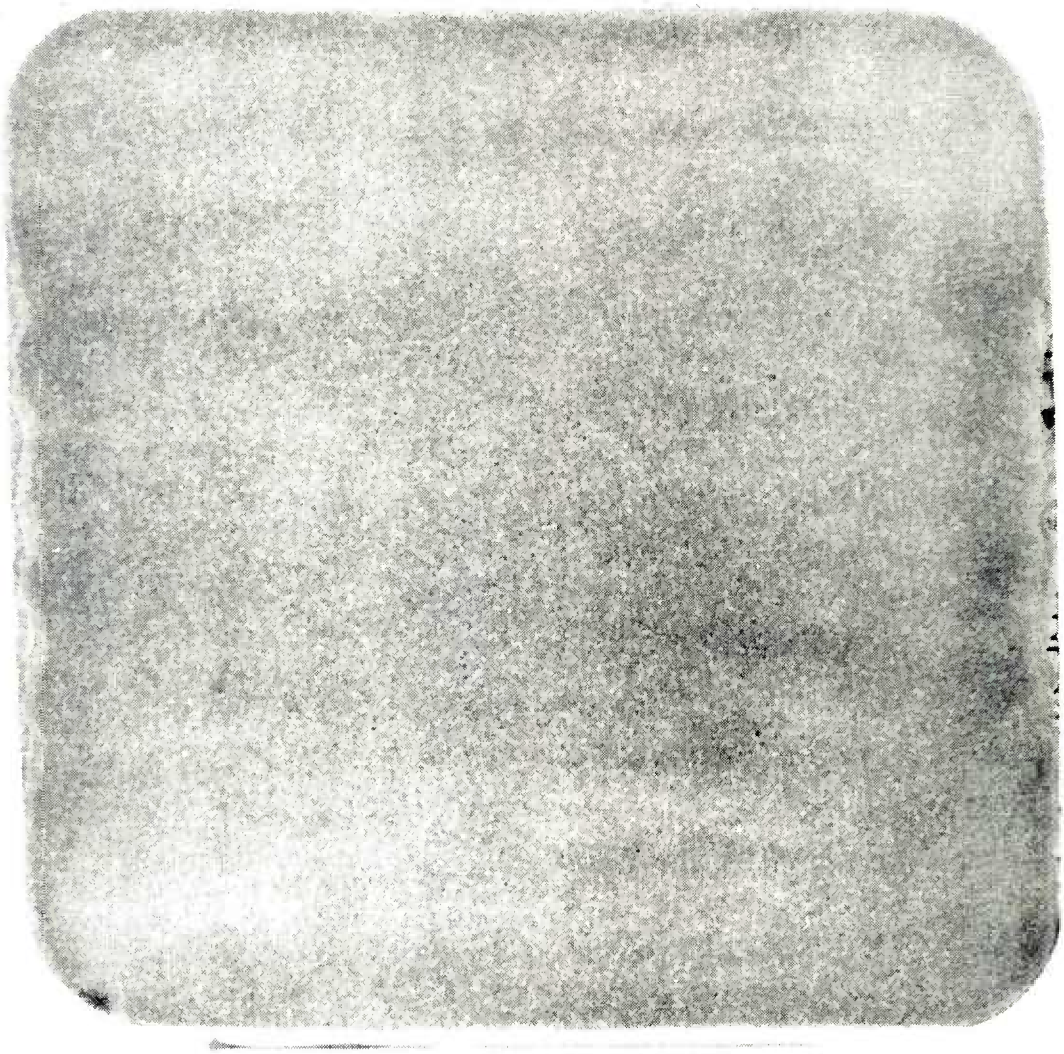


Figure D24. Billet 19X

Macro Cleanliness
Bethlehem Steel

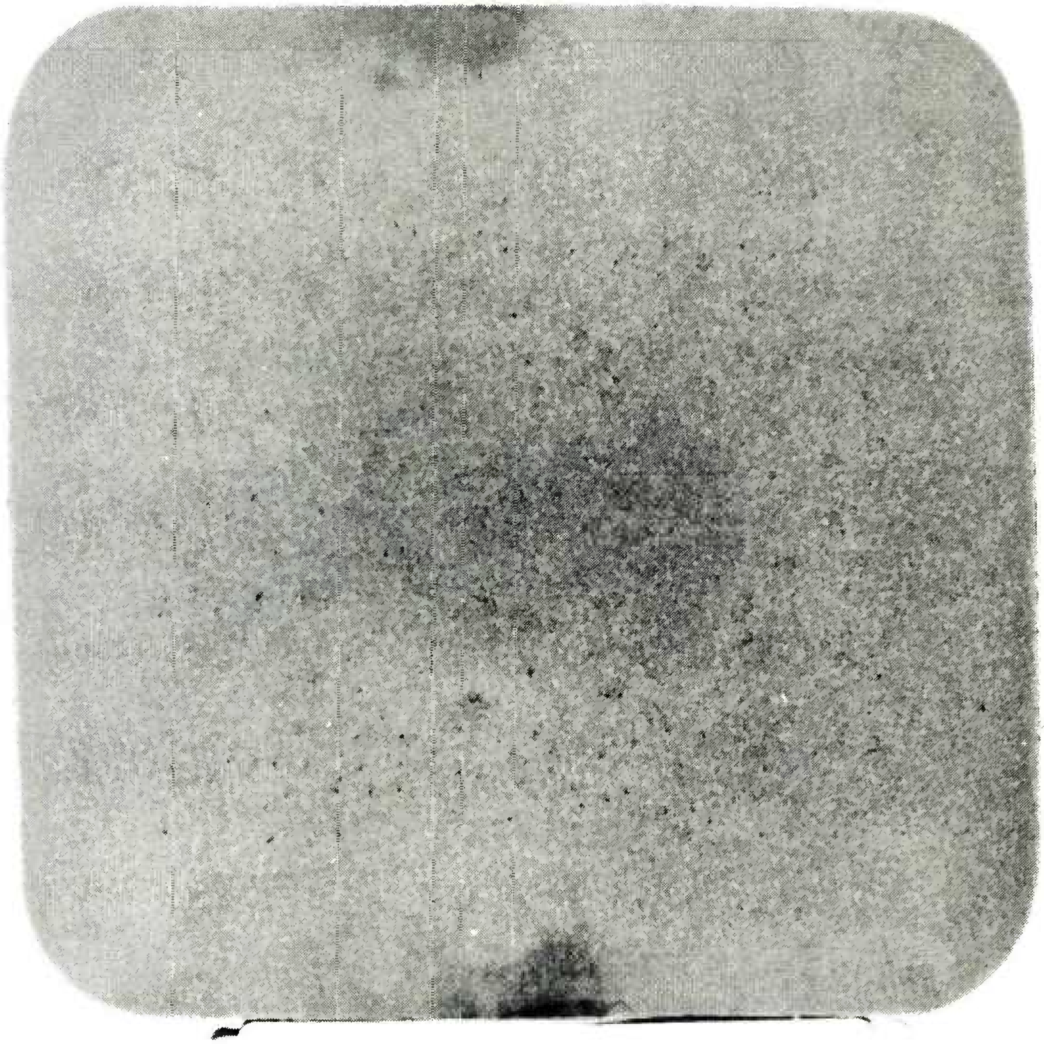


Figure D25. Billet 20T

Macro Cleanliness
Bethlehem Steel

Figure D26. Billet 20C.

Figure D27. Billet 20X.

Appendix E

Jominy Hardenability

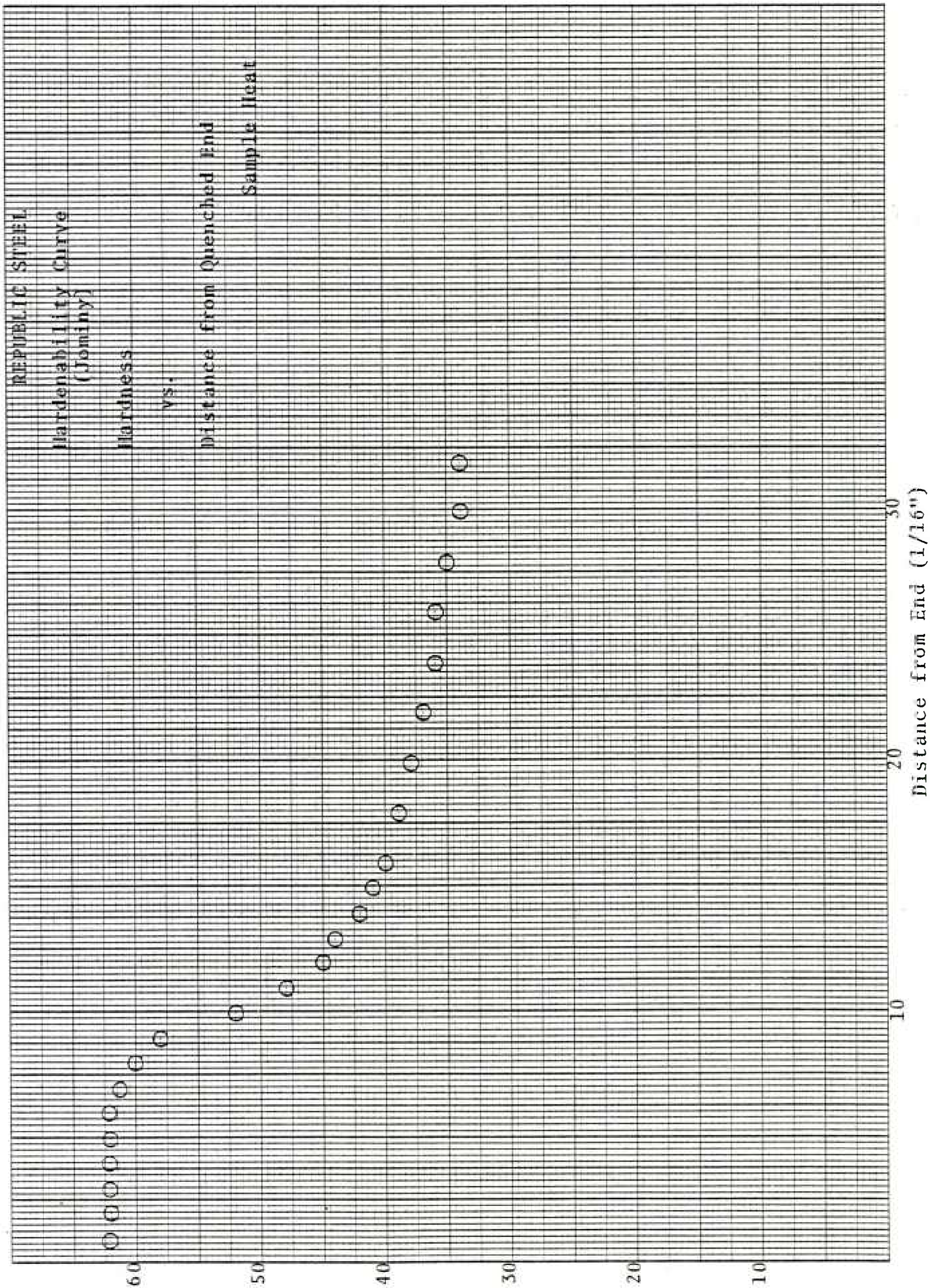

REPUBLIC STEEL
Hardenability Curve
(Jominy)
Hardness
vs.
Distance from Quenched End
Sample Heat
Distance from End (1/16")
Hardness (Rc)
10
20
30
40
50
60

Figure E1.

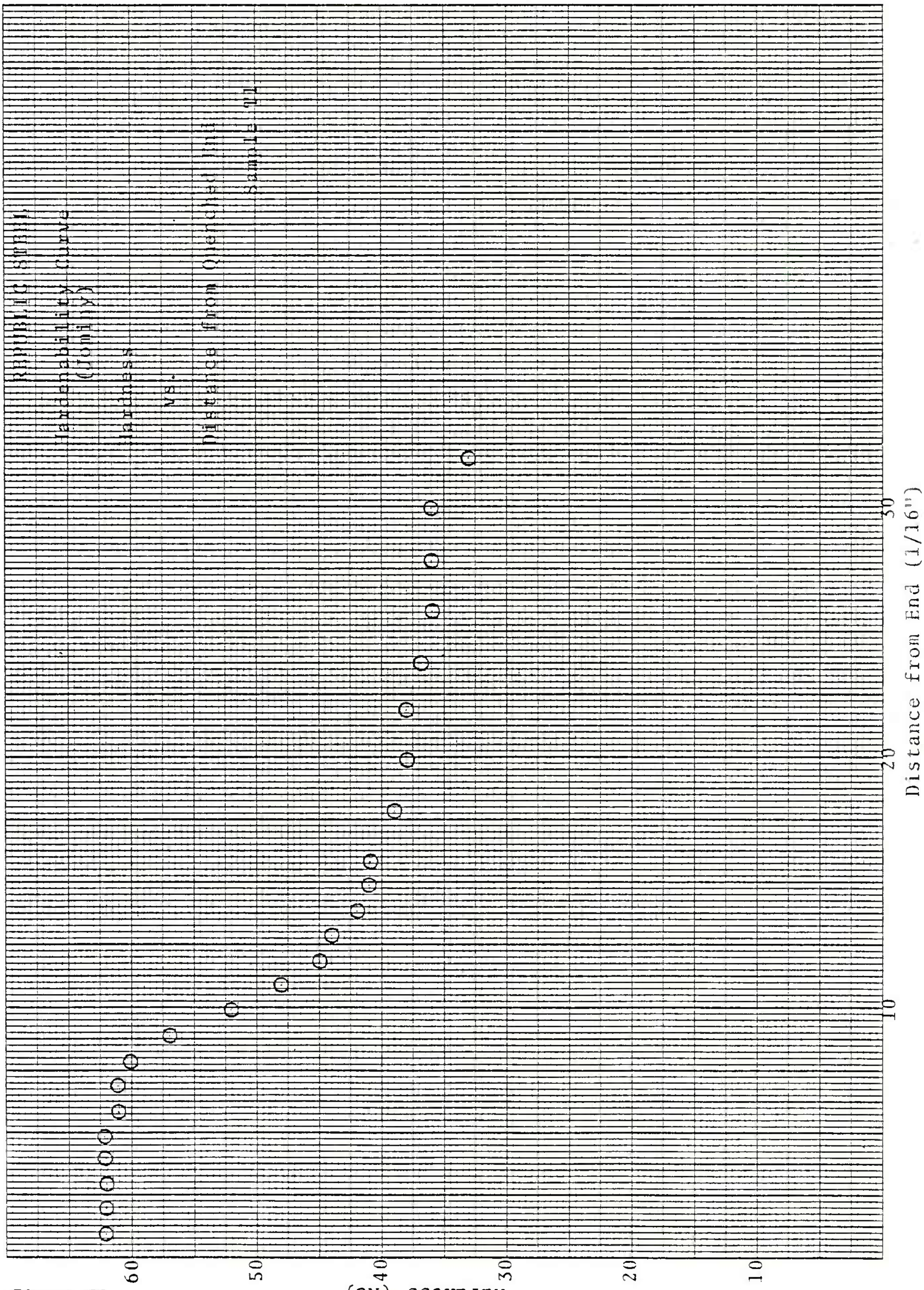

REPUBLIC STEEL
Hardenability Curve
(Jominy)
Hardness
vs.
Distance from Quenched End
Sample 41
Distance from End (1/16")
10
20
30
Hardness (Rc)
60
50
40
30
20
10

Figure E2.

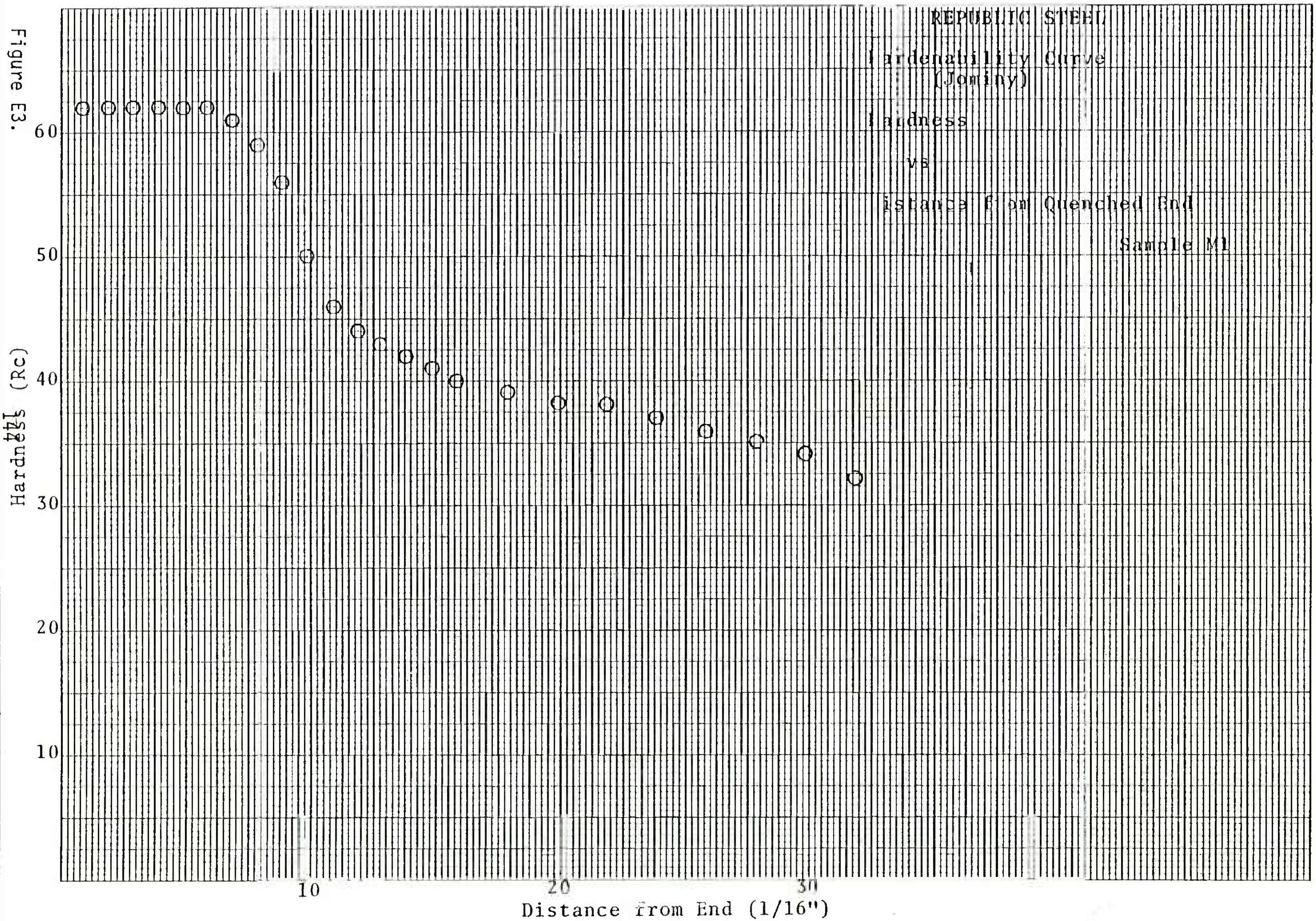

REPUBLIC
(Jominy)
vs
Quenched End
Sample M1
60
50
40
30
20
10
Hardness (Rc)
10
20
30
Distance from End (1/16")

Figure E3.

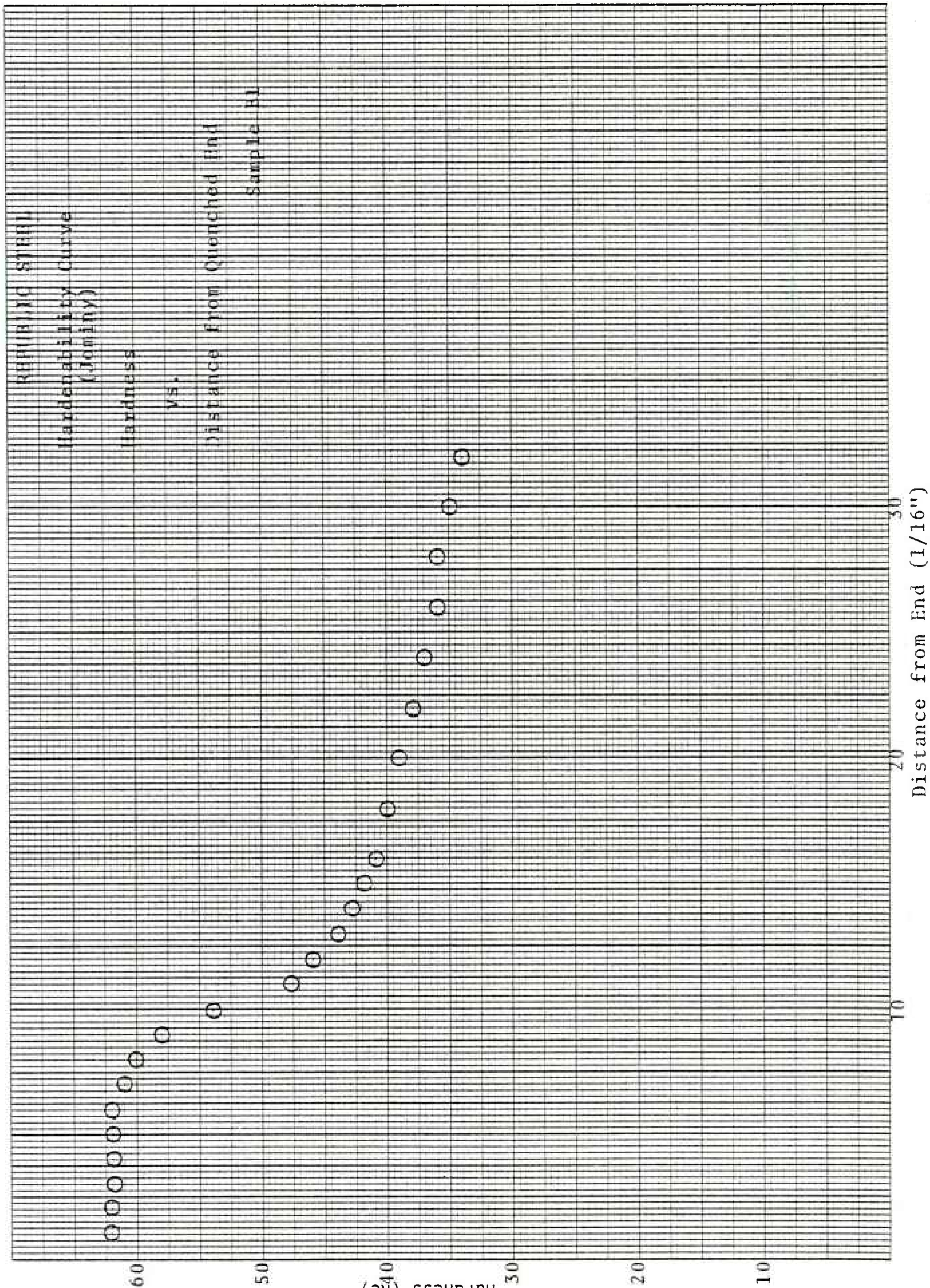

REPUBLIC STEEL
Hardenability Curve
(Jominy)
Hardness
vs.
Distance from Quenched End
Sample B1
Distance from End (1/16")
10
20
30
Hardness (Rc)
60
50
40
30
20
10

Figure E4.

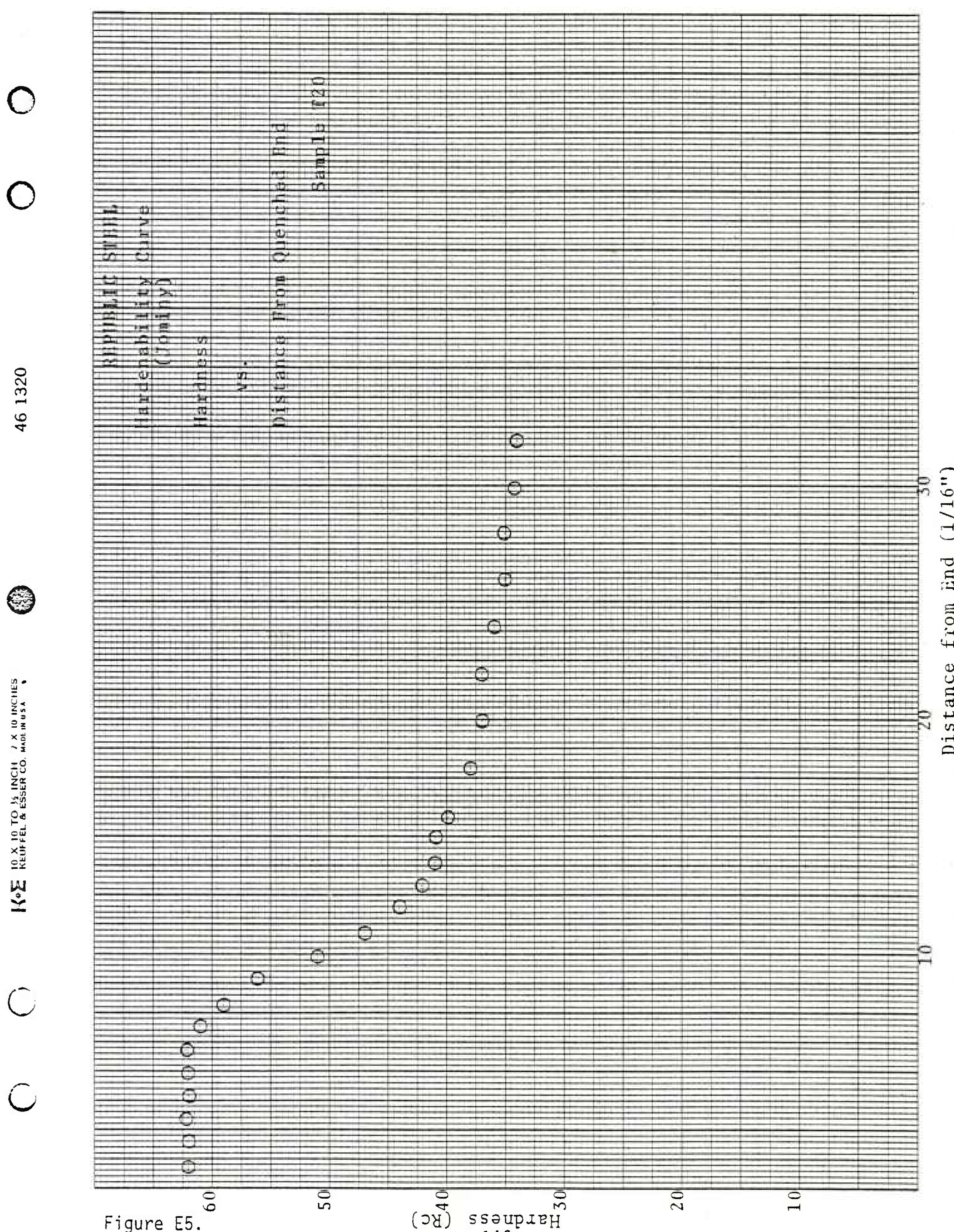

REPUBLIC STEEL
Hardenability Curve
(Jominy)
Hardness
vs.
Distance From Quenched End
Sample #20
Hardness (Rc)
Distance from End (1/16")
60
50
40
30
20
10
10
20
30
K+E 10 X 10 TO ½ INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1320

Figure E5.

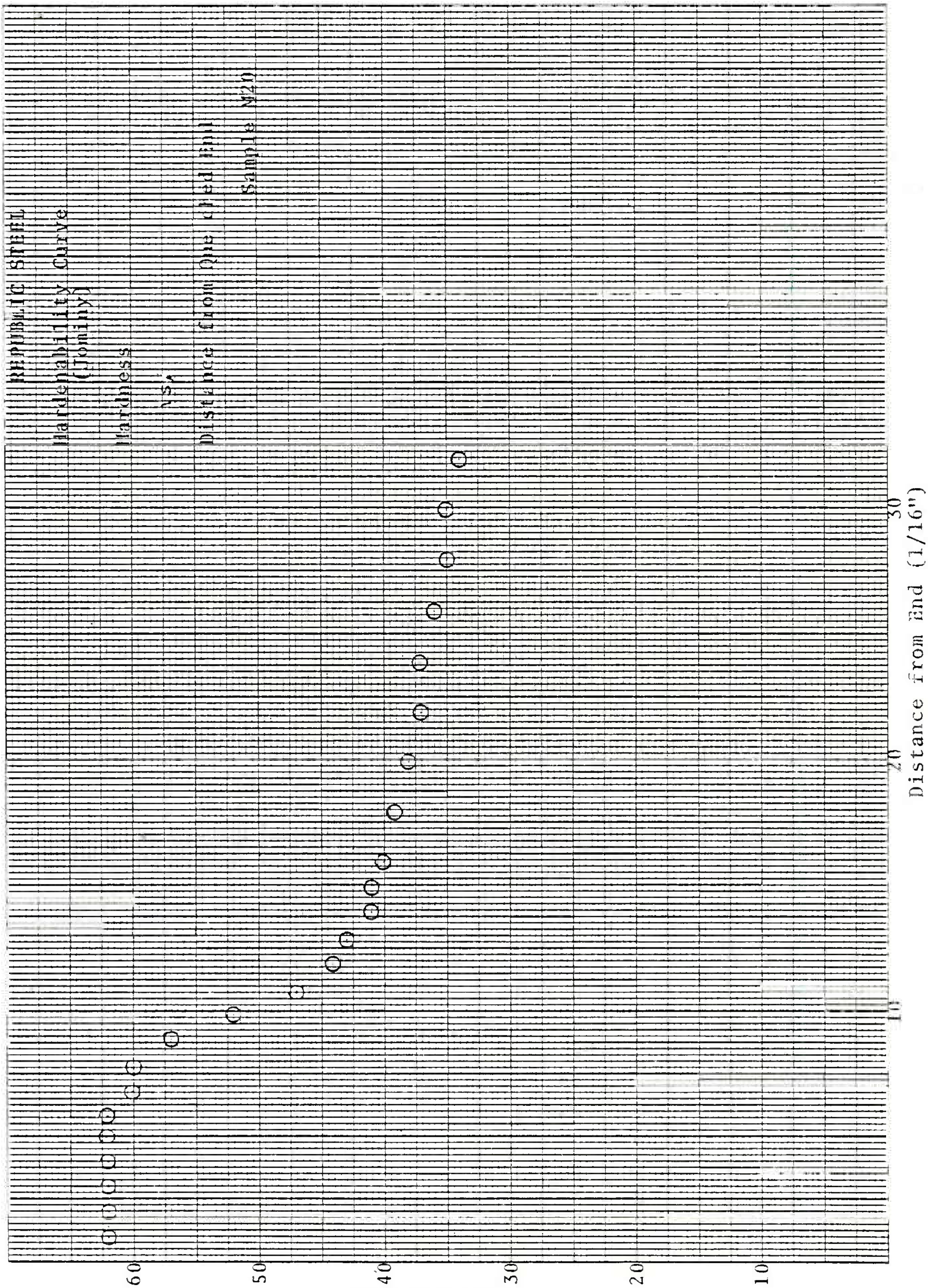

REPUBLIC STEEL
Hardenability Curve
(Jominy)
Hardness
vs.
Distance from Que ched End
Sample M20
Distance From End (1/16")
10
20
30
Hardness (Rc)
60
50
40
30
20
10

Figure E6.

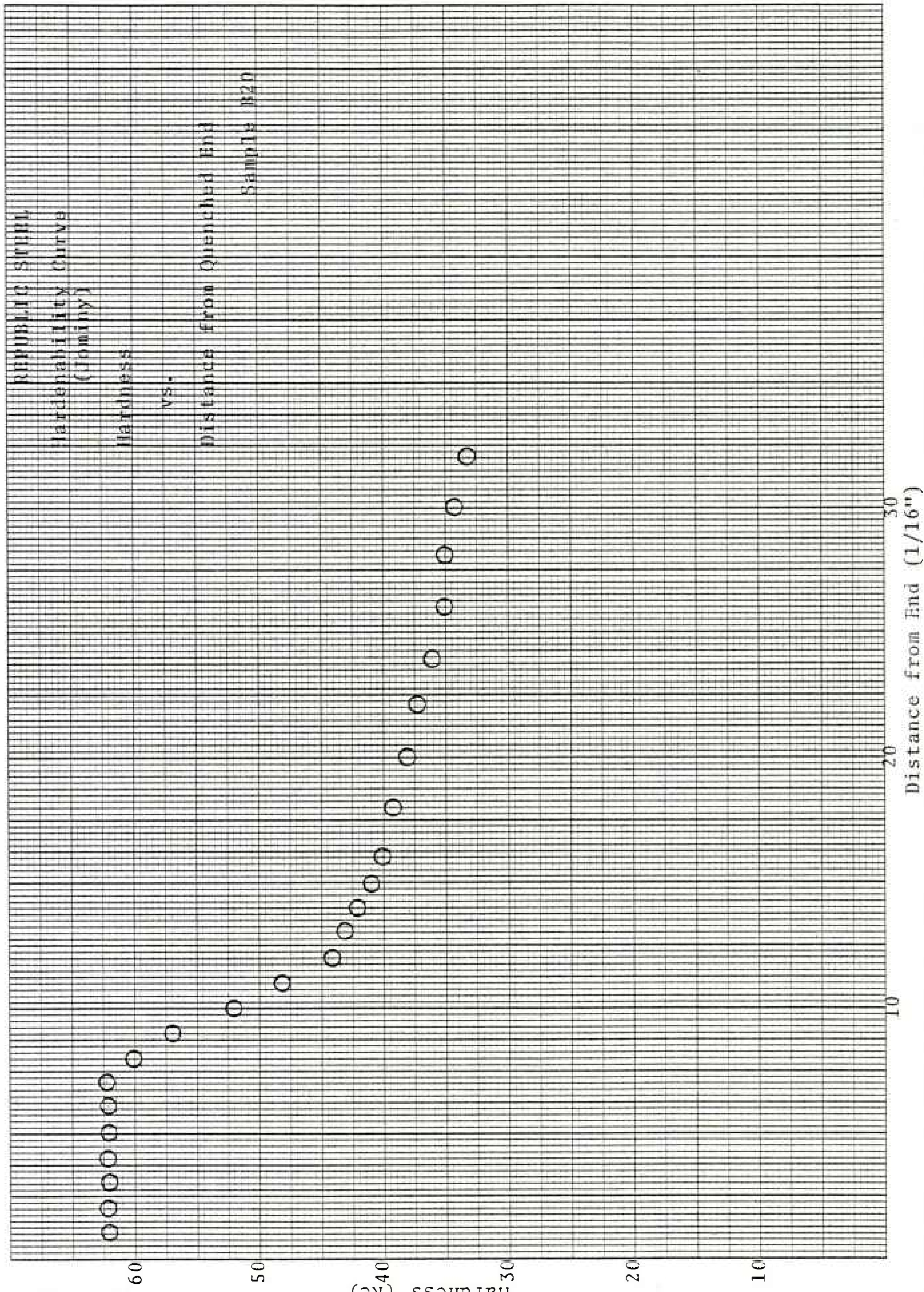

REPUBLIC STEEL
Hardenability Curve
(Jominy)
Hardness
vs.
Distance from Quenched End
Sample 1320
Distance from End (1/16")
10
20
30
Hardness (Rc)
60
50
40
30
20
10

Figure E7.

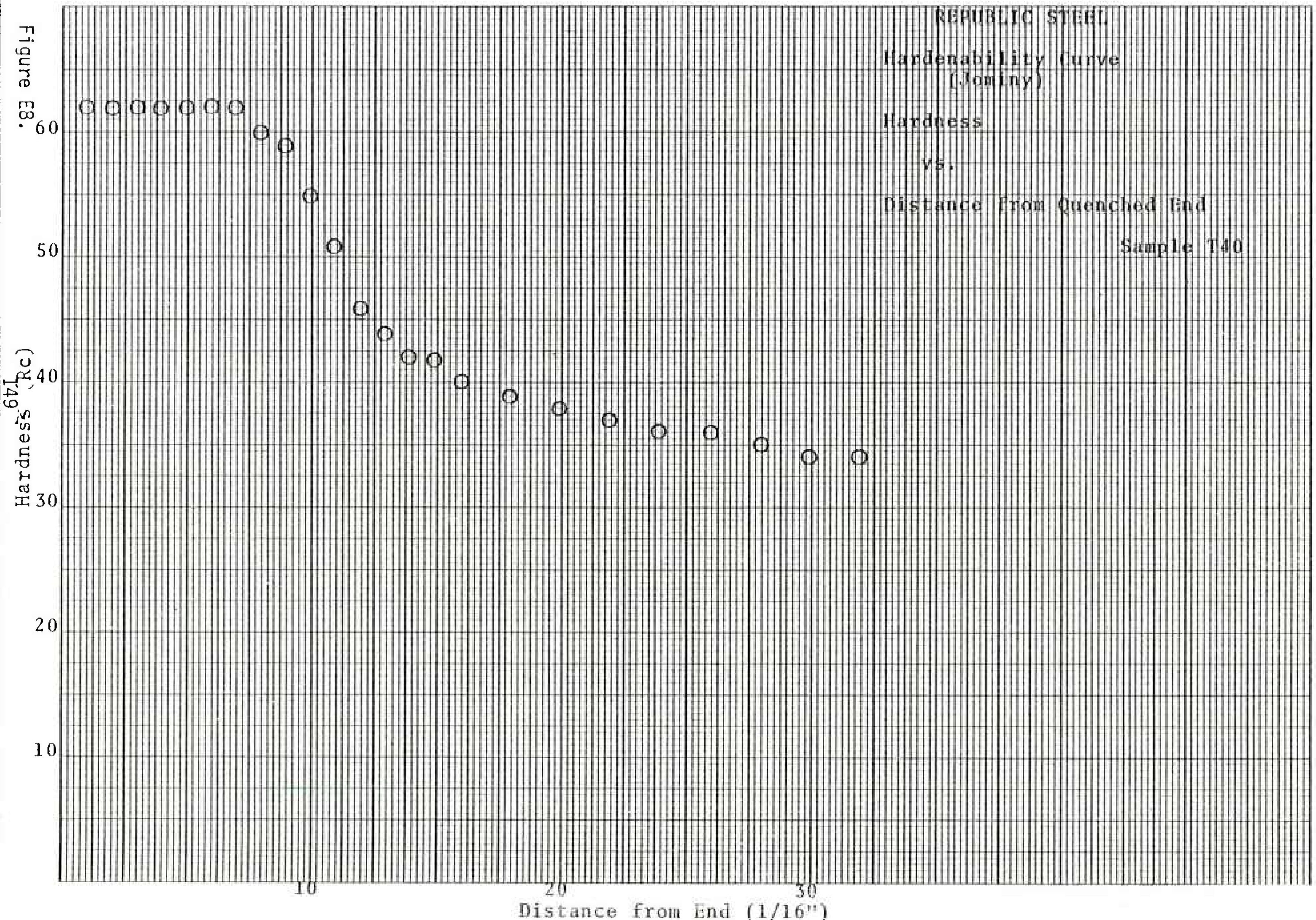

REPUBLIC STEEL
Hardenability Curve (Jominy)
Hardness
vs.
Distance from Quenched End
Sample T40
Hardness (Rc)
60
50
40
30
20
10
Distance from End (1/16")
10
20
30

Figure E8.

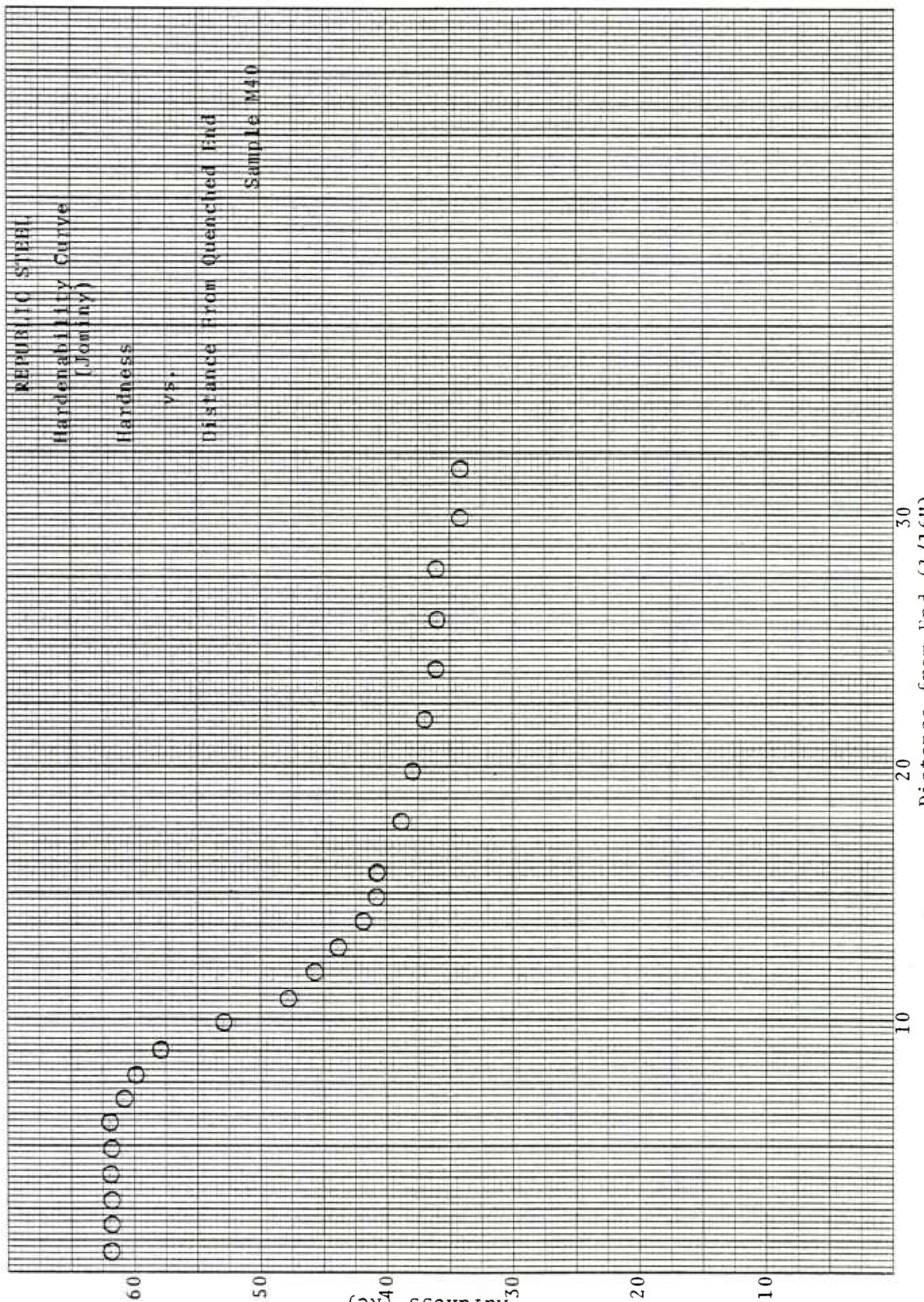

REPUBLIC STEEL
Hardenability Curve
(Jominy)
Hardness
vs.
Distance From Quenched End
Sample M40
60
50
40
30
20
10
Hardness (Rc)
10
20
30
Distance from End (1/16")

Figure E9.

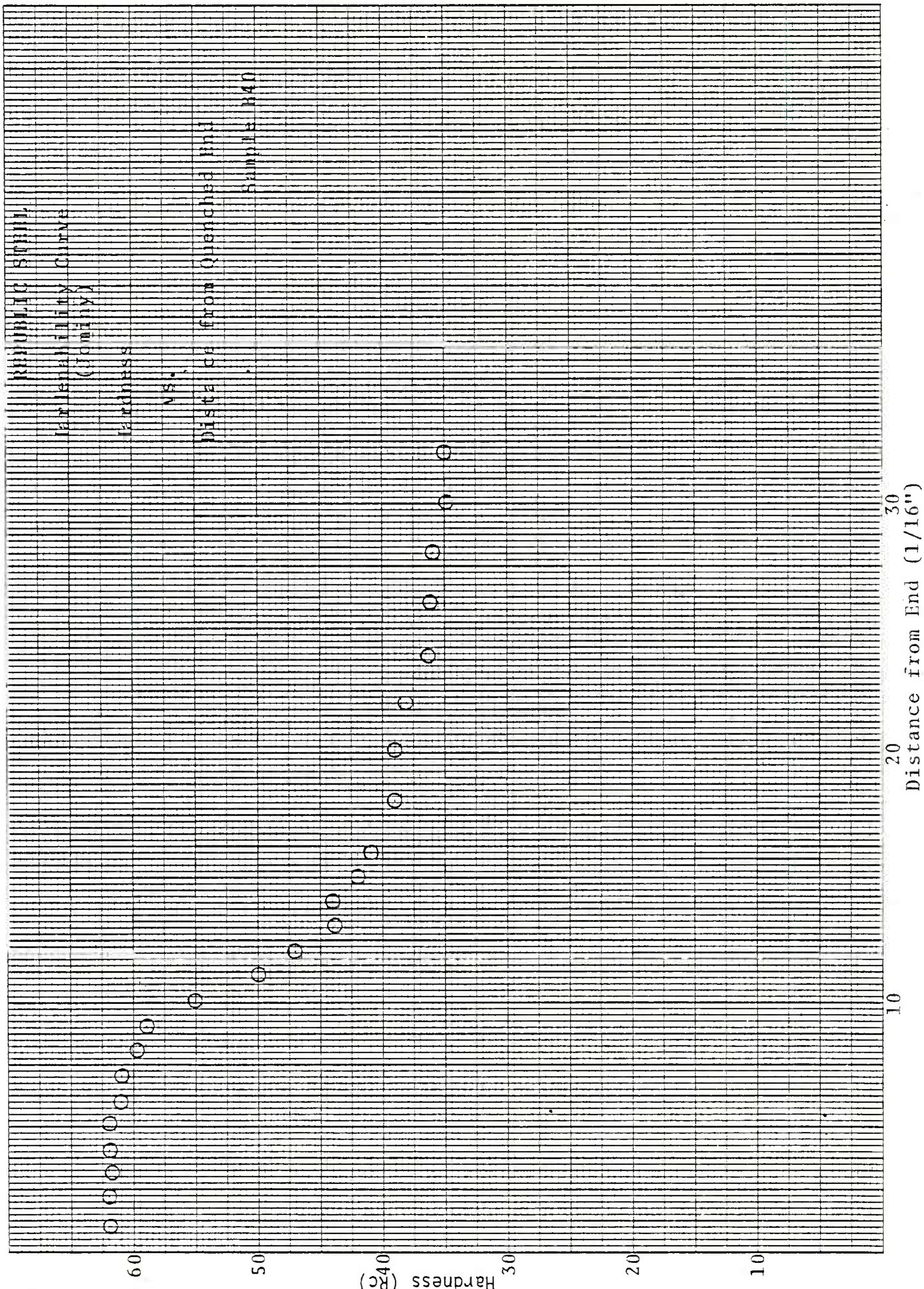

REPUBLIC STEEL
Hardenability Curve
(Jominy)
Hardness
vs.
Distance from Quenched End
Sample H40
Distance from End (1/16")
10
20
30
Hardness (Rc)
10
20
30
40
50
60

Figure E10.

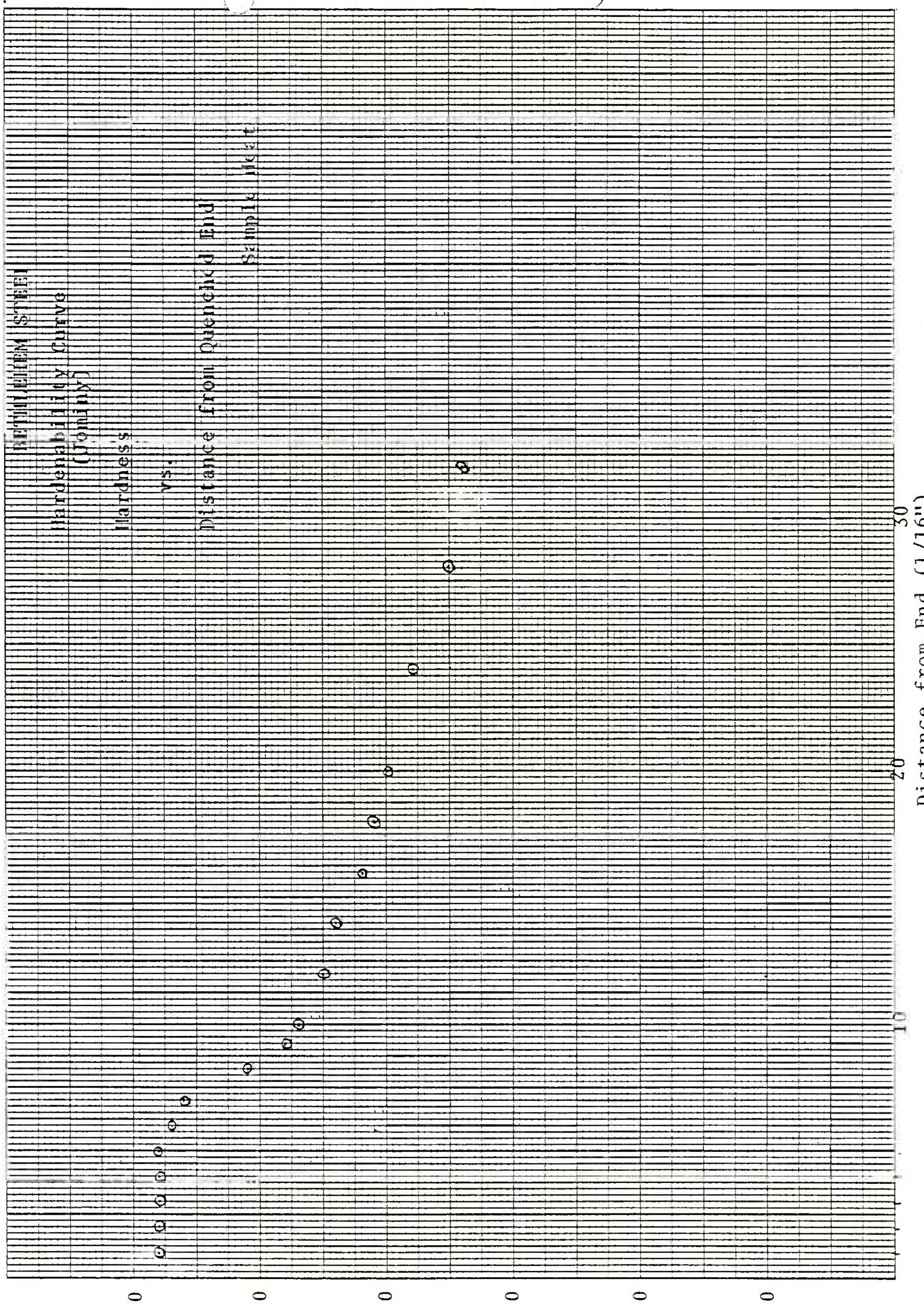
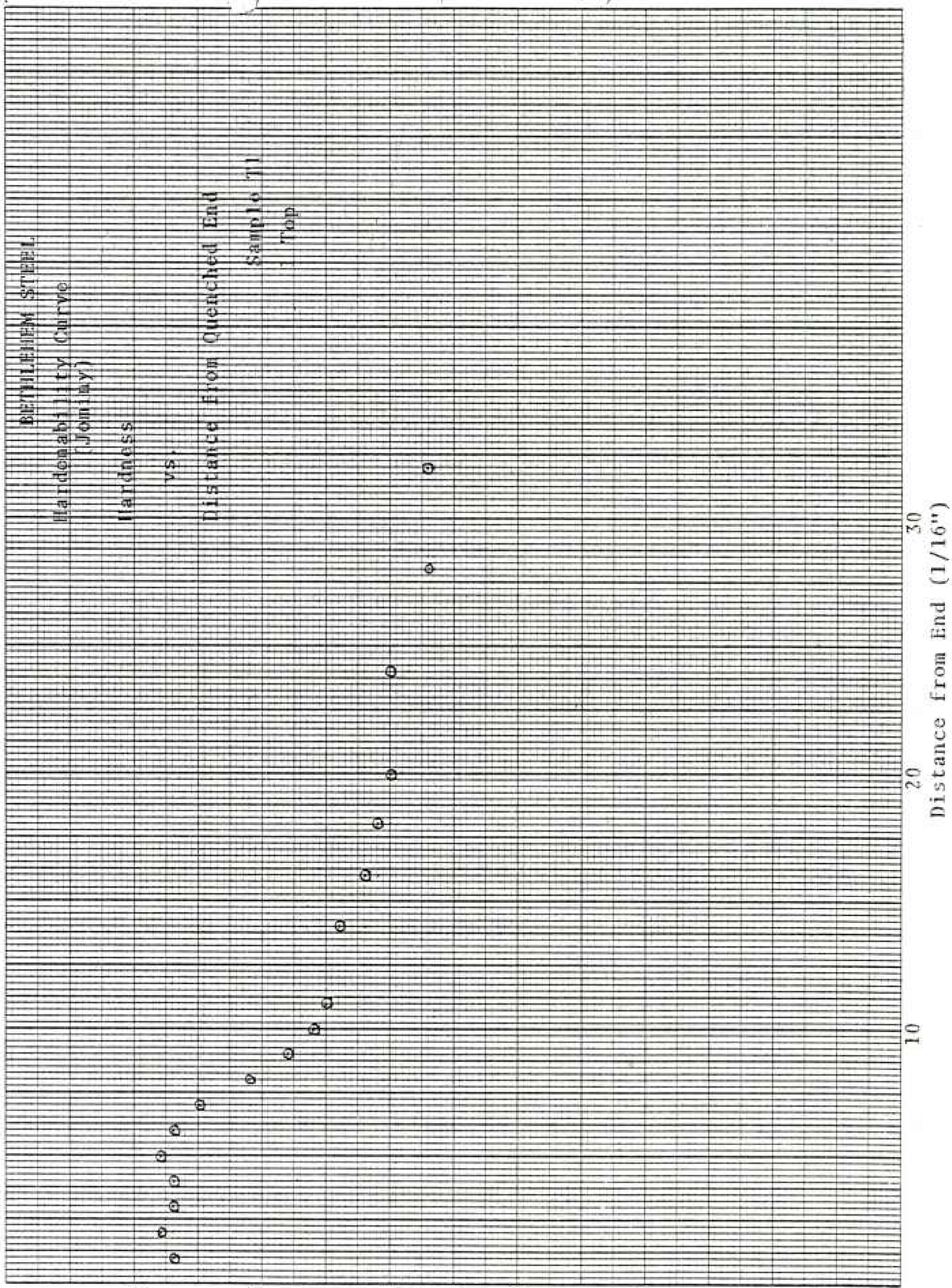

BETHLEHEM STEEL
Hardenability Curve
(Jominy)
Hardness
vs.
Distance from Quenched End
Sample Heat
Distance from End (1/16")
10
20
30
Hardness (Rc)
60
50
40
30
20
10

Figure E11.



K&E 10 X 10 TO ½ INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN USA 46 1320

Figure E12.

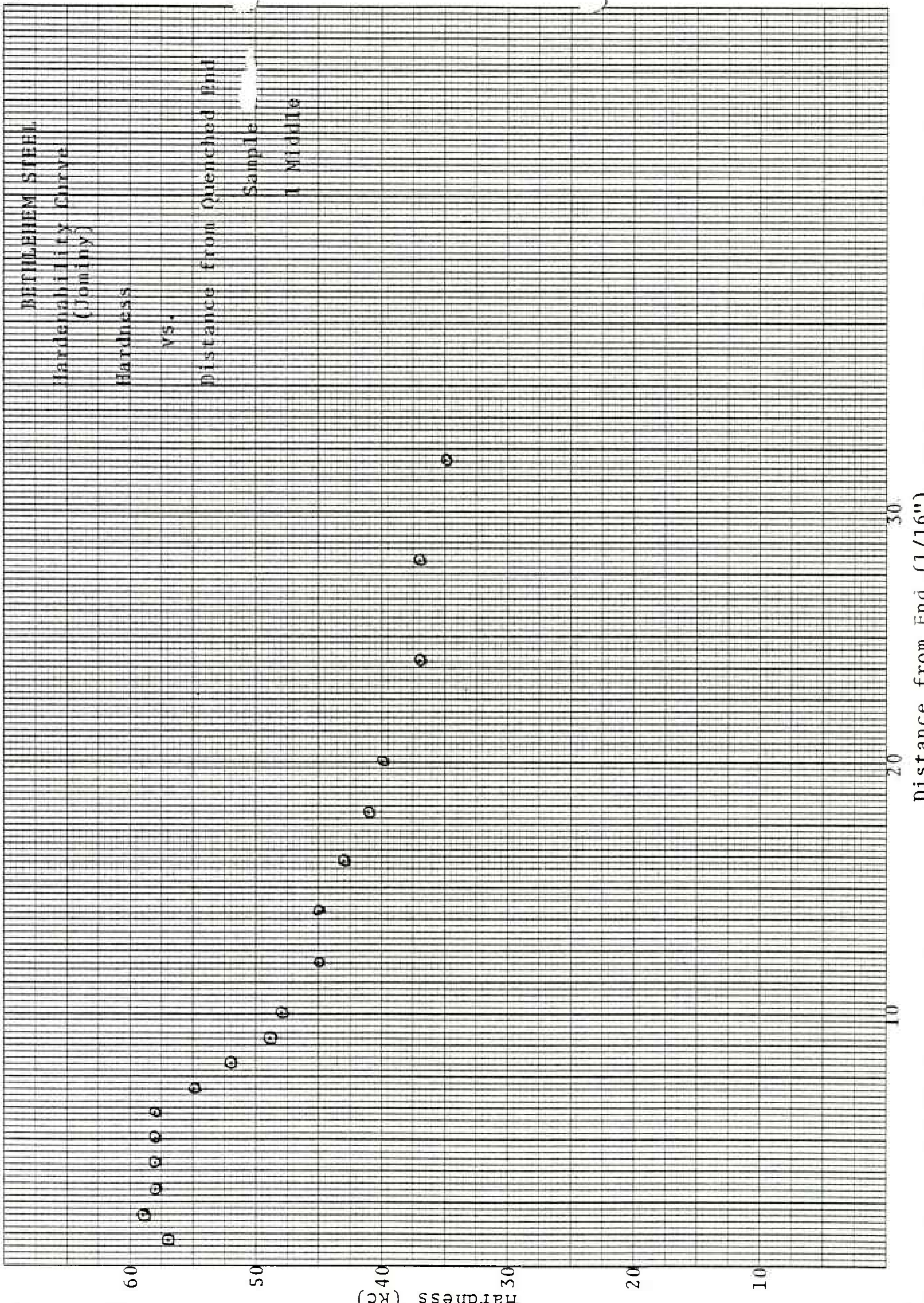

BETHLEHEM STEEL
Hardenability Curve
(Jominy)
Hardness
vs.
Distance from Quenched End
Sample
1 Middle
Hardness (Rc)
60
50
40
30
20
10
Distance from End (1/16")
10
20
30

Figure E13.

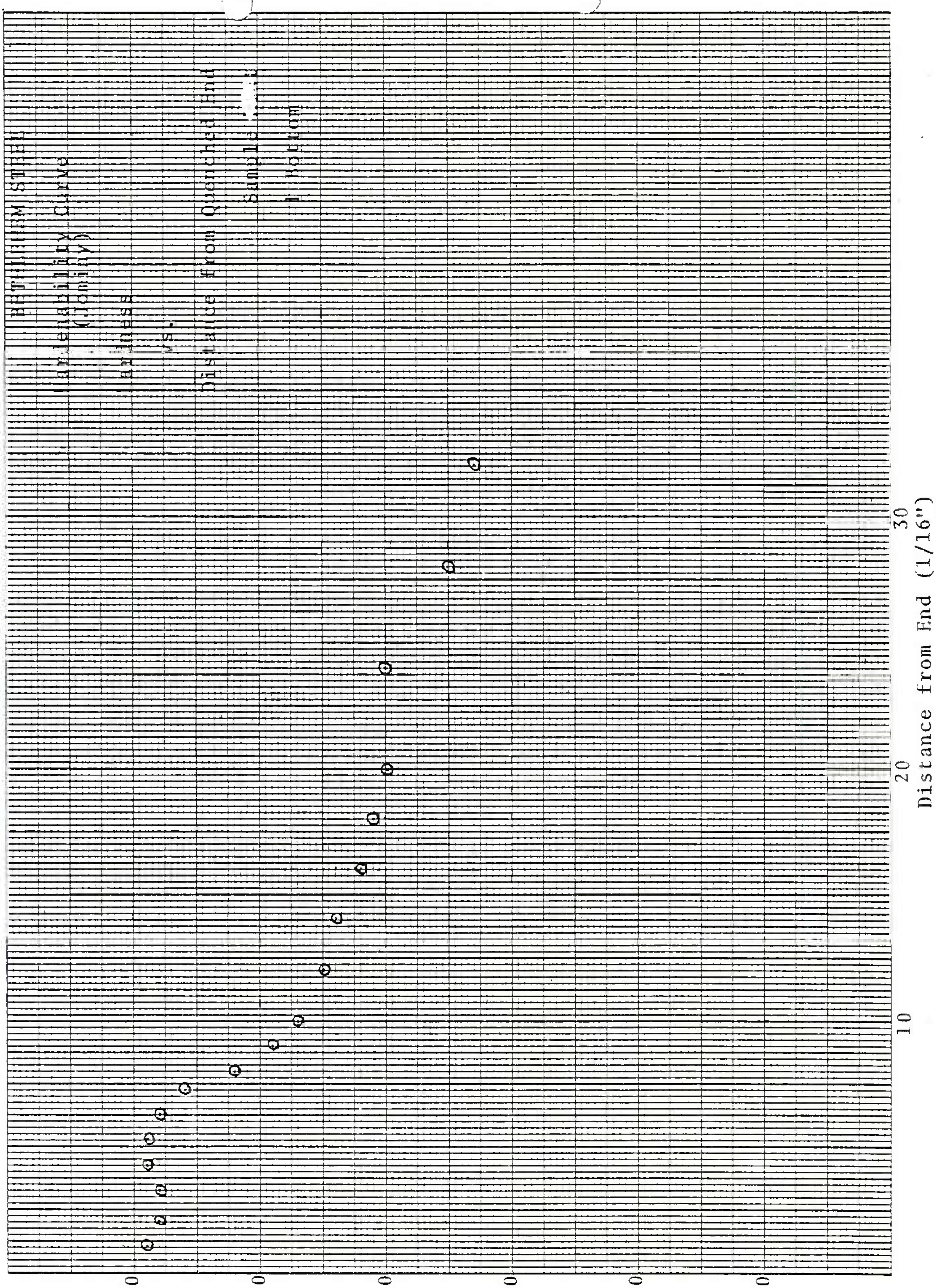

BETHLEHEM STEEL
Hardenability Curve
(Jominy)
Hardness
vs.
Distance from Quenched End
Sample
Bottom
Distance from End (1/16")
10
20
30
Hardness (Rc)
60
50
40
30
20
10
K+E 10 X 10 TO 1/2 INCH 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1320

Figure E14.

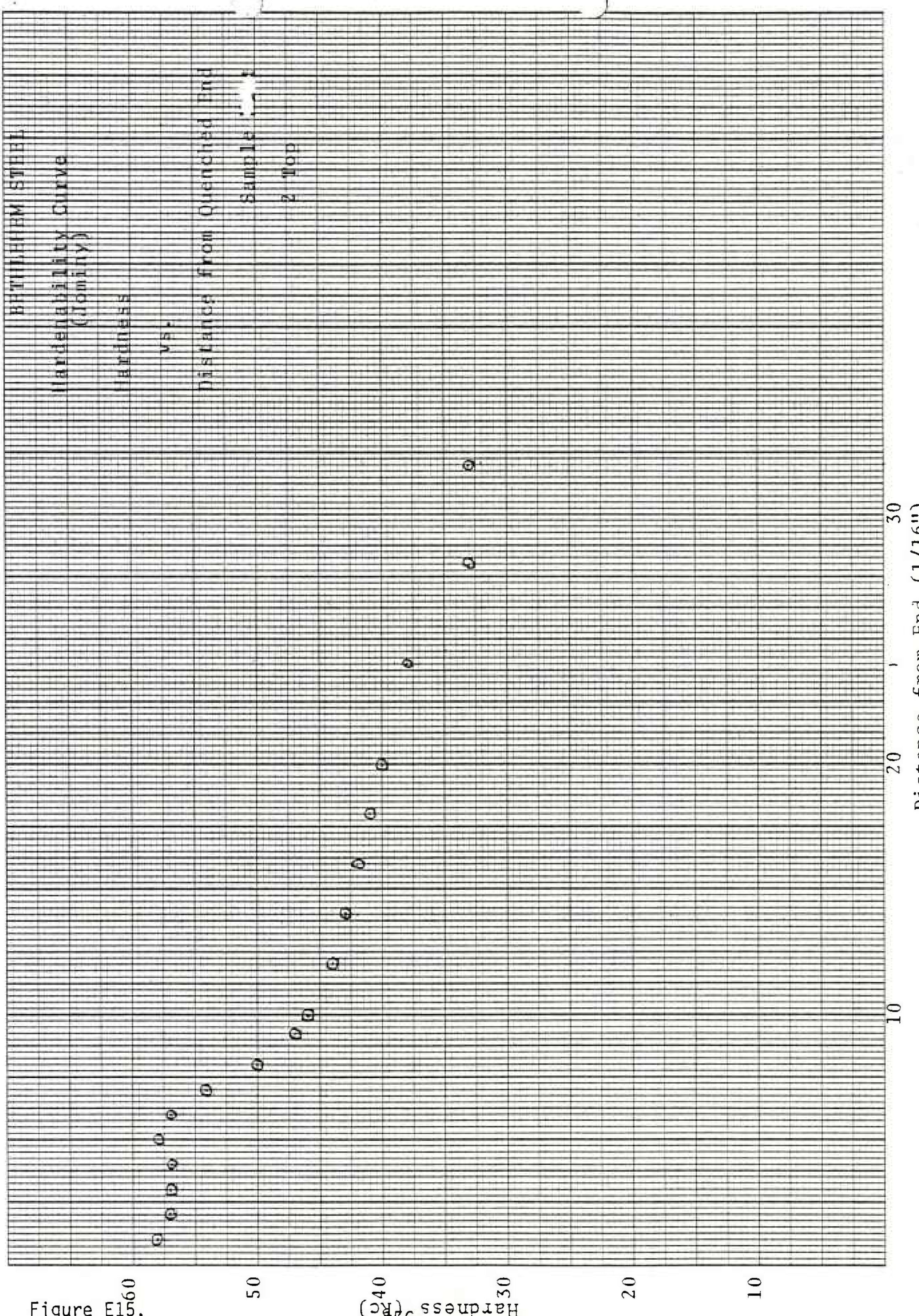

BETHLEHEM STEEL
Hardenability Curve
(Jominy)
Hardness
vs.
Distance from Quenched End
Sample
2 Top
60
50
40
30
20
10
10
20
30
Distance from End (1/16")
Hardness (Rc)

Figure E15.

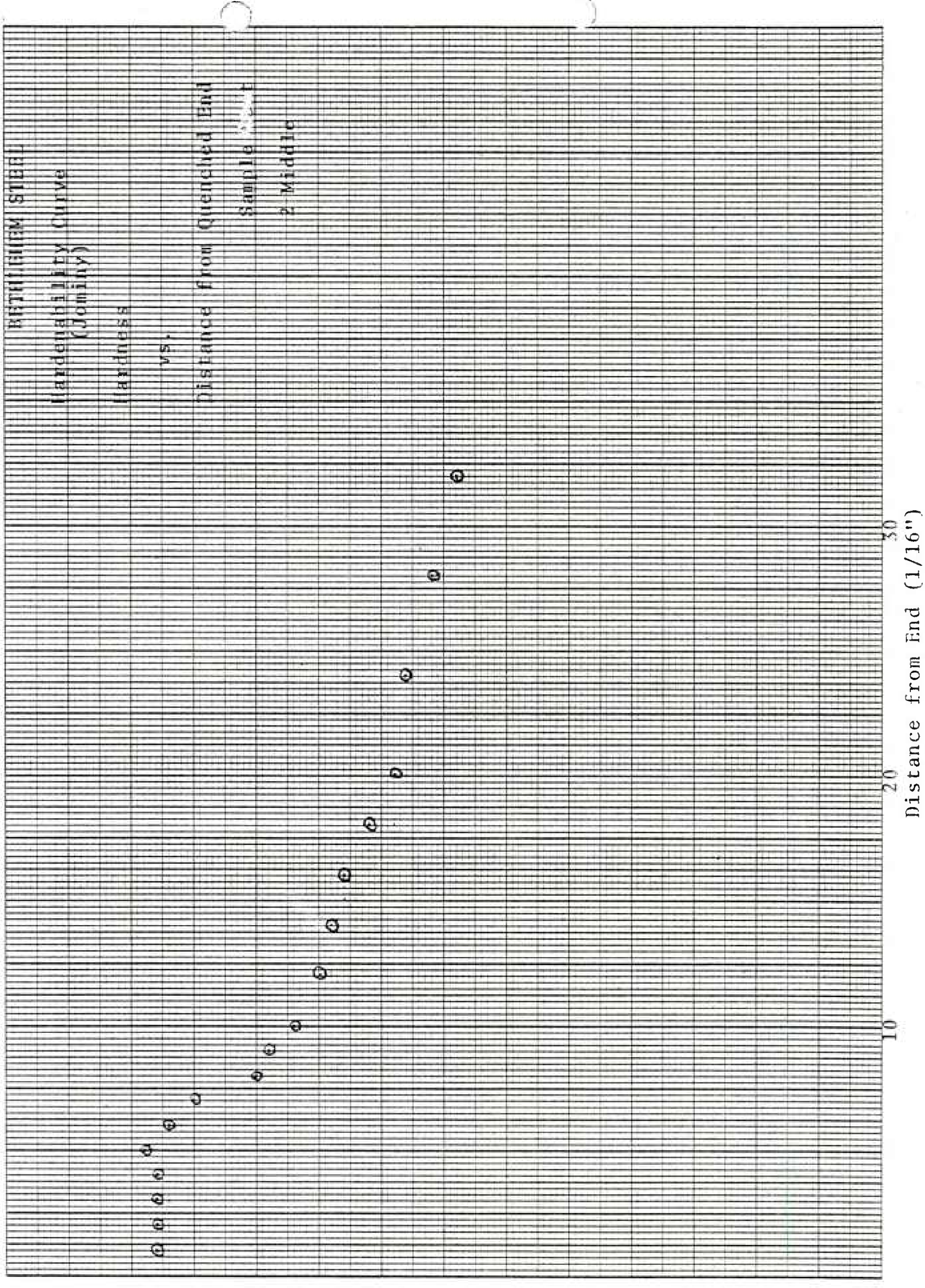

BETHLEHEM STEEL
Hardenability Curve (Jominy)
Hardness
vs.
Distance from Quenched End
Sample E
2 Middle
Distance from End (1/16")
10
20
30
Hardness (Rc)
60
50
40
30
20
10

Figure E16.

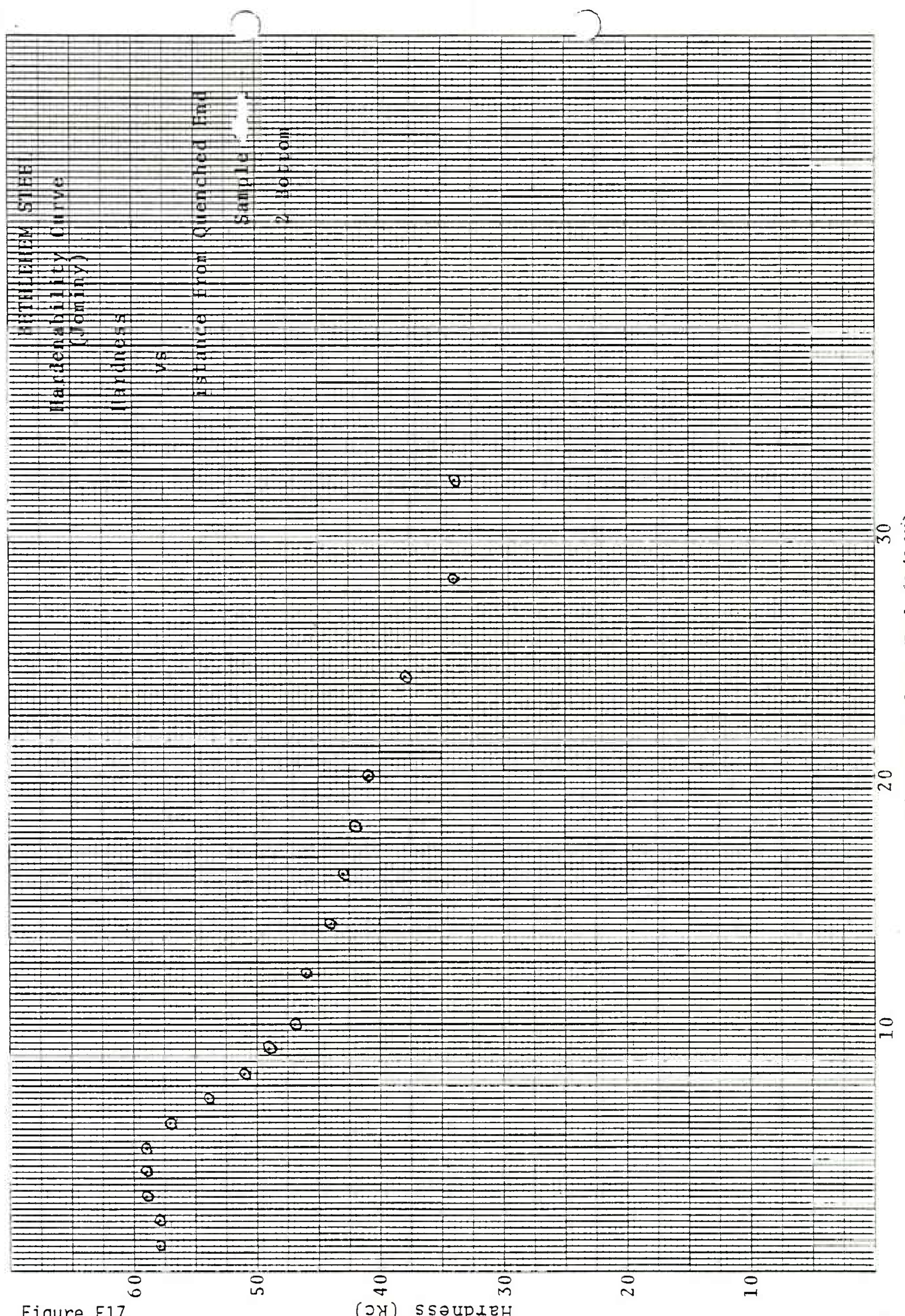

BETHLEHEM STEEL
Hardenability Curve
(Jominy)
Hardness
vs
Distance From Quenched End
Sample
2 Bottom
10
20
30
Distance from End (1/16")
60
50
40
30
20
10
Hardness (Rc)

Figure E17.

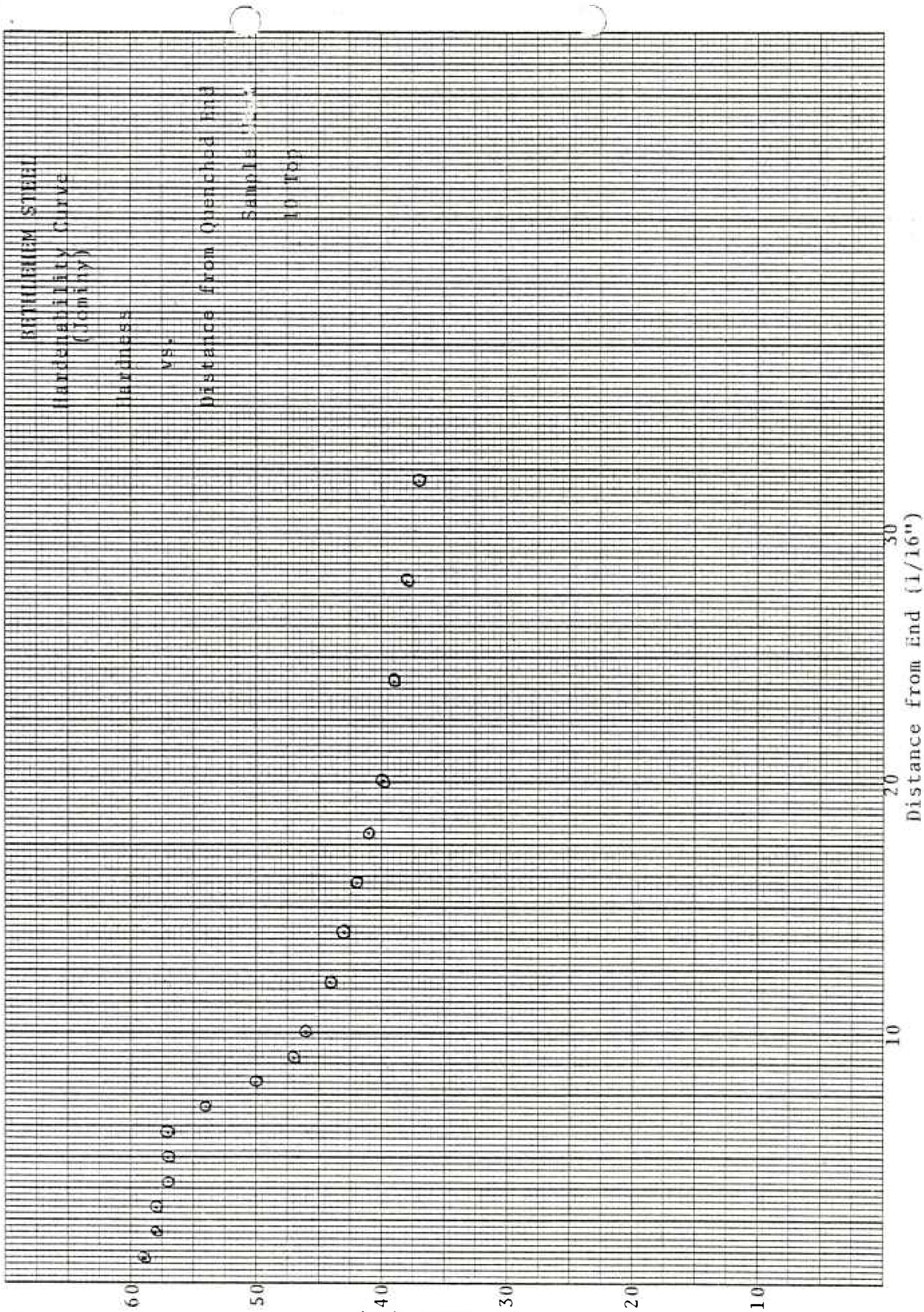

BETHLEHEM STEEL
Hardenability Curve
(Jominy)
Hardness
vs.
Distance from Quenched End
Sample
10 Top
Distance from End (1/16")
10
20
30
Hardness (Rc)
60
50
40
30
20
10

Figure E18.

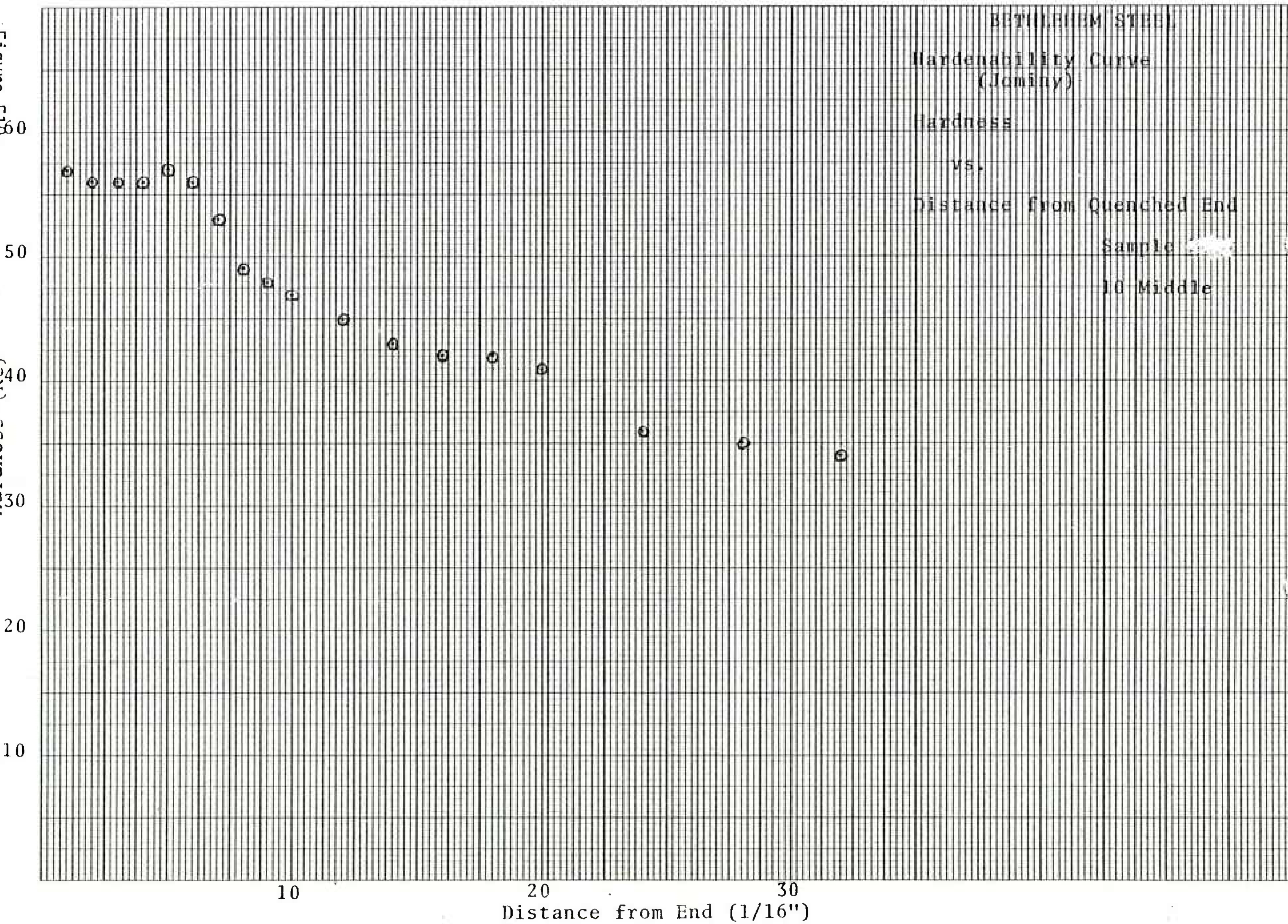

BETHLEHEM STEEL
Hardenability Curve
(Jominy)
Hardness
vs.
Distance from Quenched End
Sample
10 Middle
60
50
40
30
20
10
Hardness (Rc)
10
20
30
Distance from End (1/16")

Figure E19.

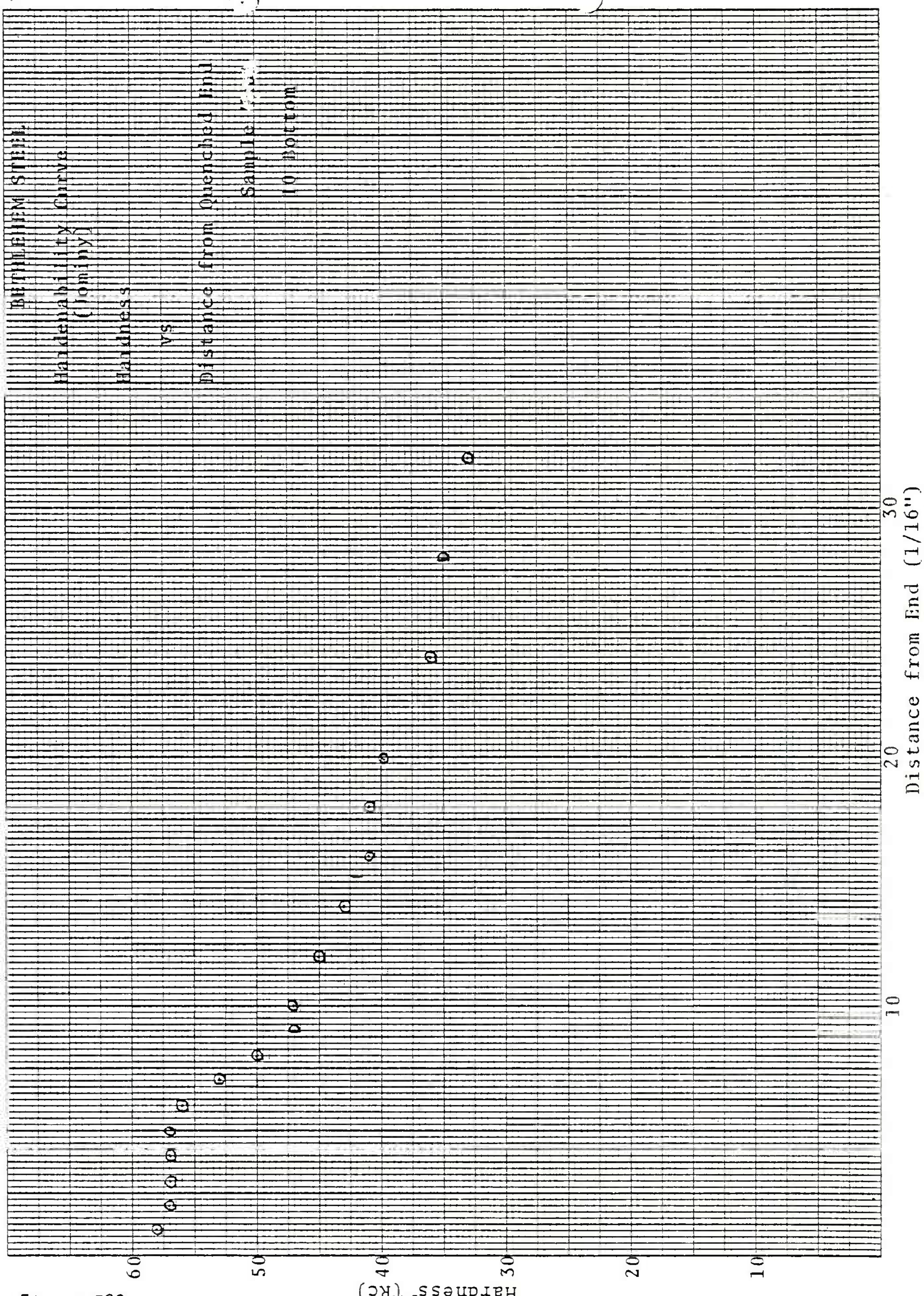

BETHLEHEM STEEL
Hardenability Curve
(Jominy)
Hardness
vs
Distance from Quenched End
Sample
10 Bottom
60
50
40
30
20
10
Hardness (Rc)
10
20
30
Distance from End (1/16")

Figure E20.

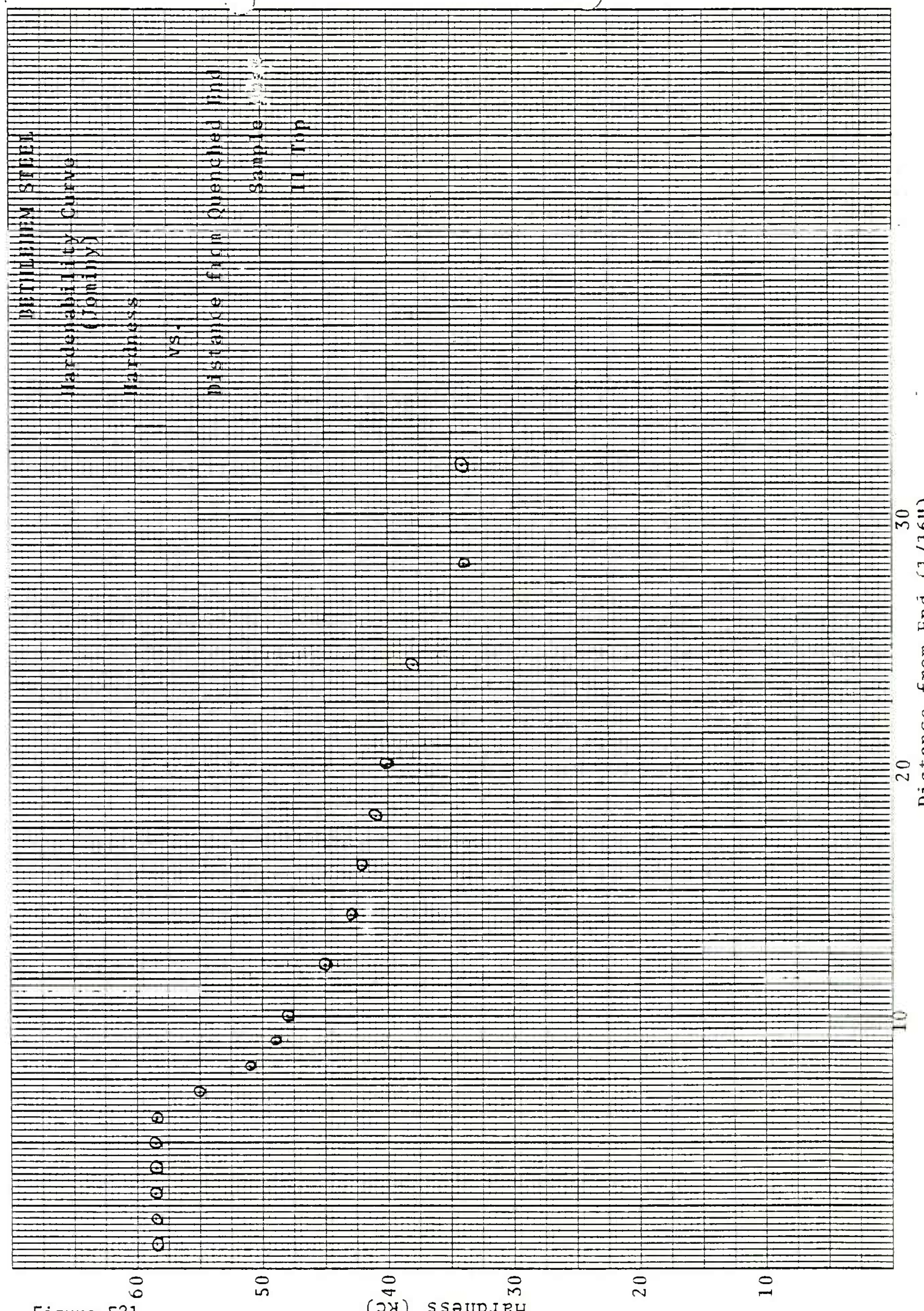

BETHLEHEM STEEL
Hardenability Curve (Jominy)
Hardness vs. Distance from Quenched End
Sample
11 Top
Hardness (Rc)
Distance from End (1/16")
60
50
40
30
20
10
10
20
30

Figure E21.

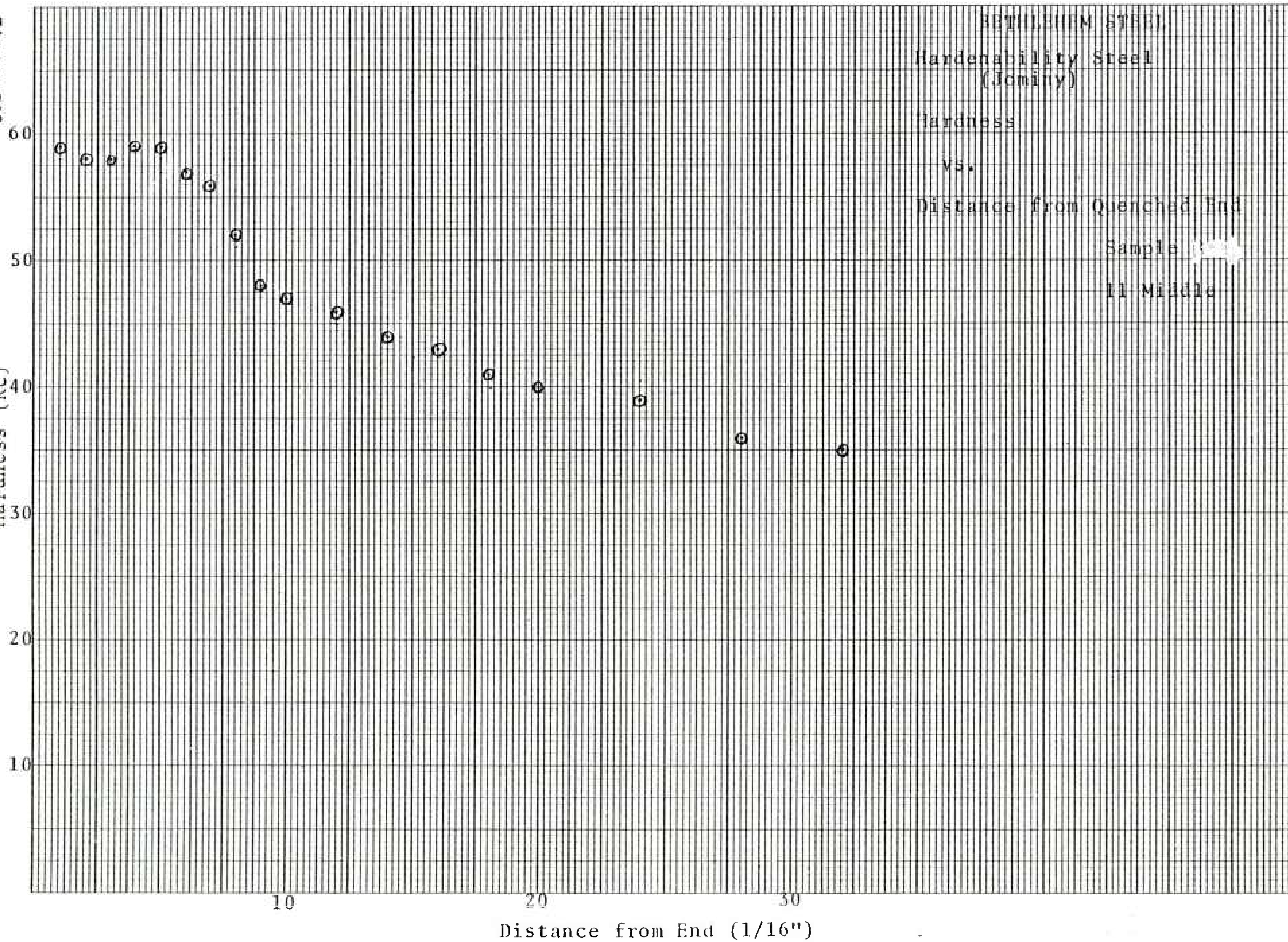

BETHLEHEM STEEL
Hardenability Steel
(Jominy)
Hardness
vs.
Distance from Quenched End
Sample
11 Middle
60
50
40
30
20
10
Hardness (Rc)
10
20
30
Distance from End (1/16")

Figure E22.

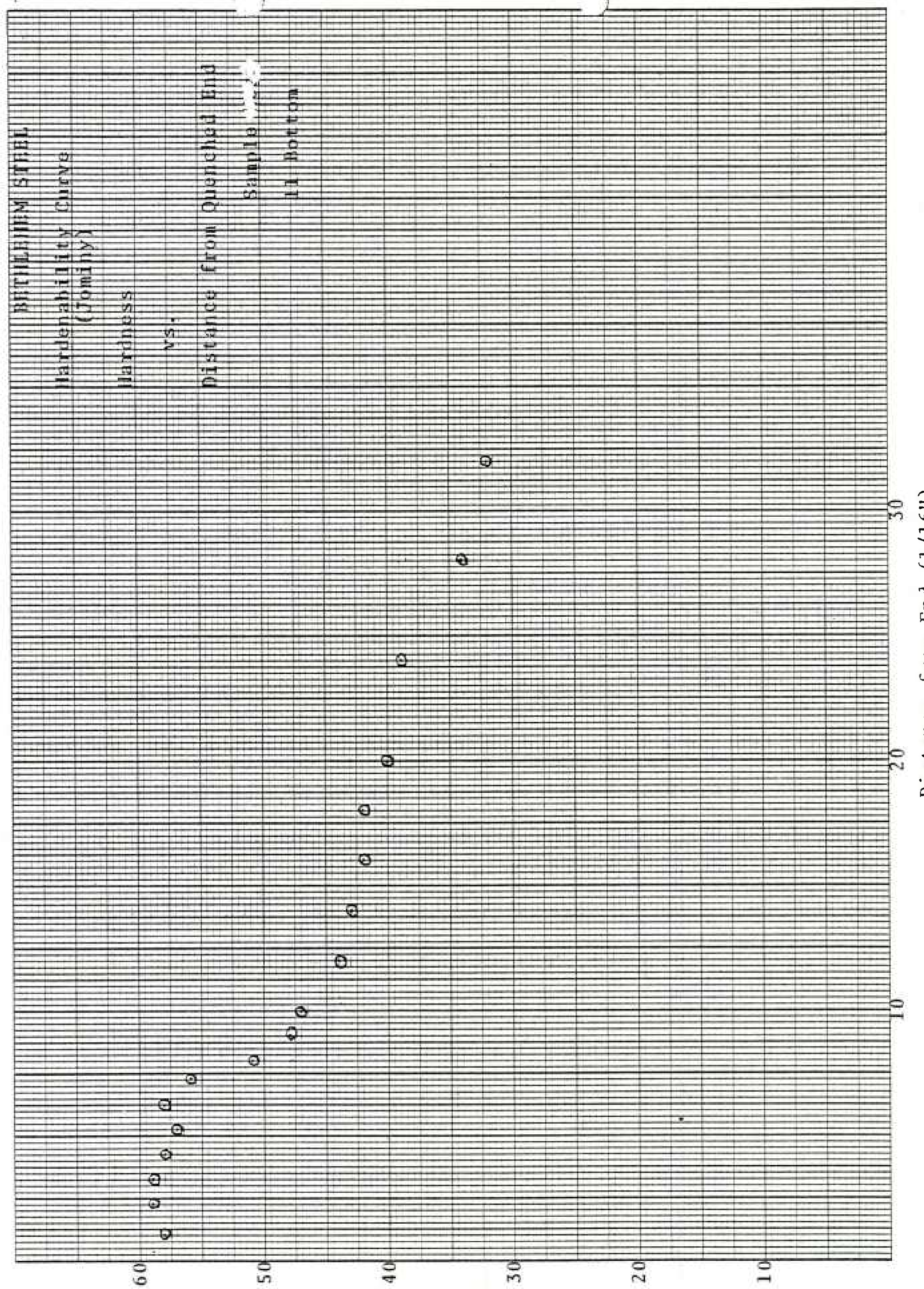

BETHLEHEM STEEL
Hardenability Curve
(Jominy)
Hardness
vs.
Distance from Quenched End
Sample
11 Bottom
10
20
30
Distance from End (1/16")
60
50
40
30
20
10
Hardness (Rc)

Figure E23.

K+E 10 X 10 TO ½ INCH 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

46 1320

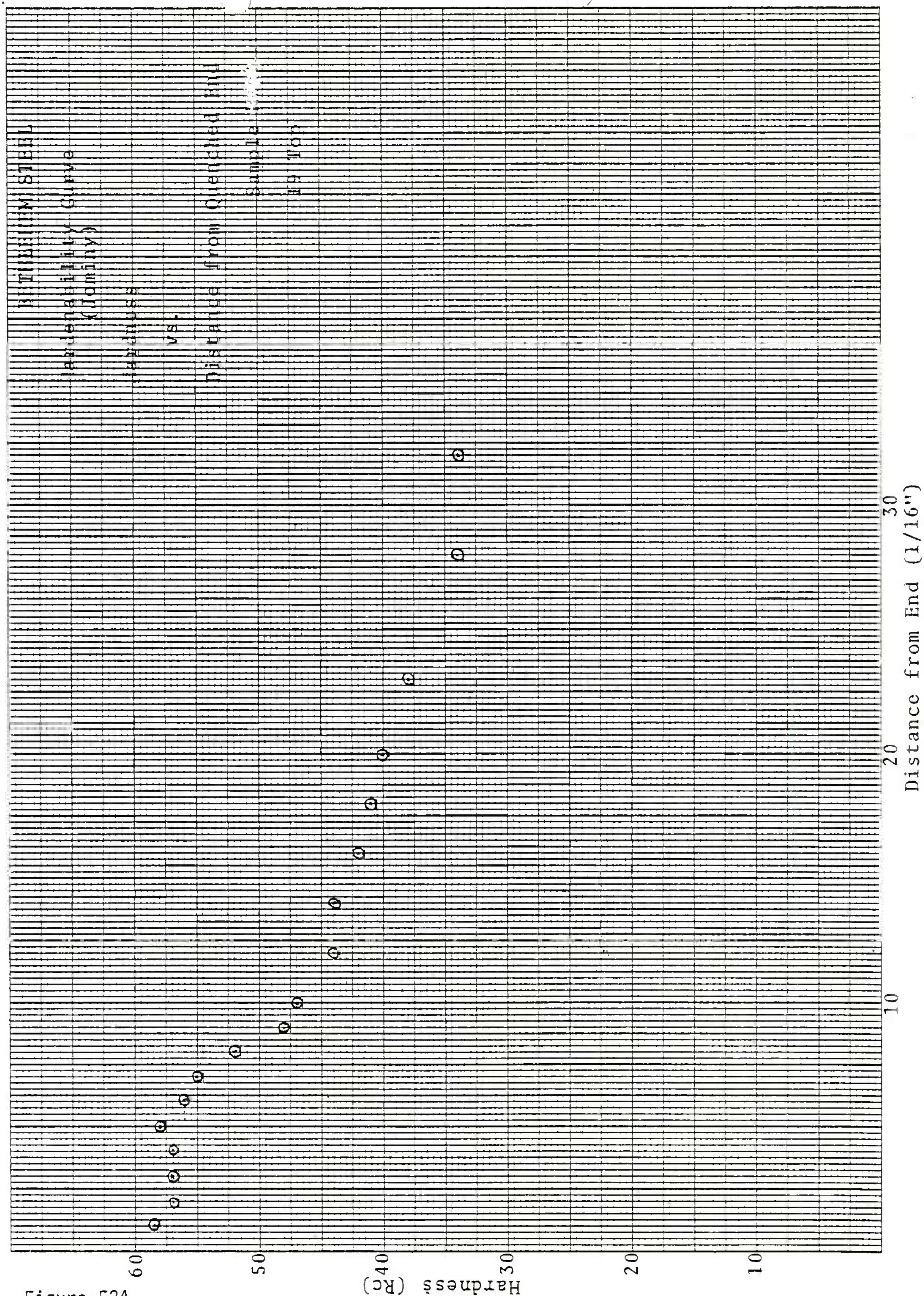


Figure E24.

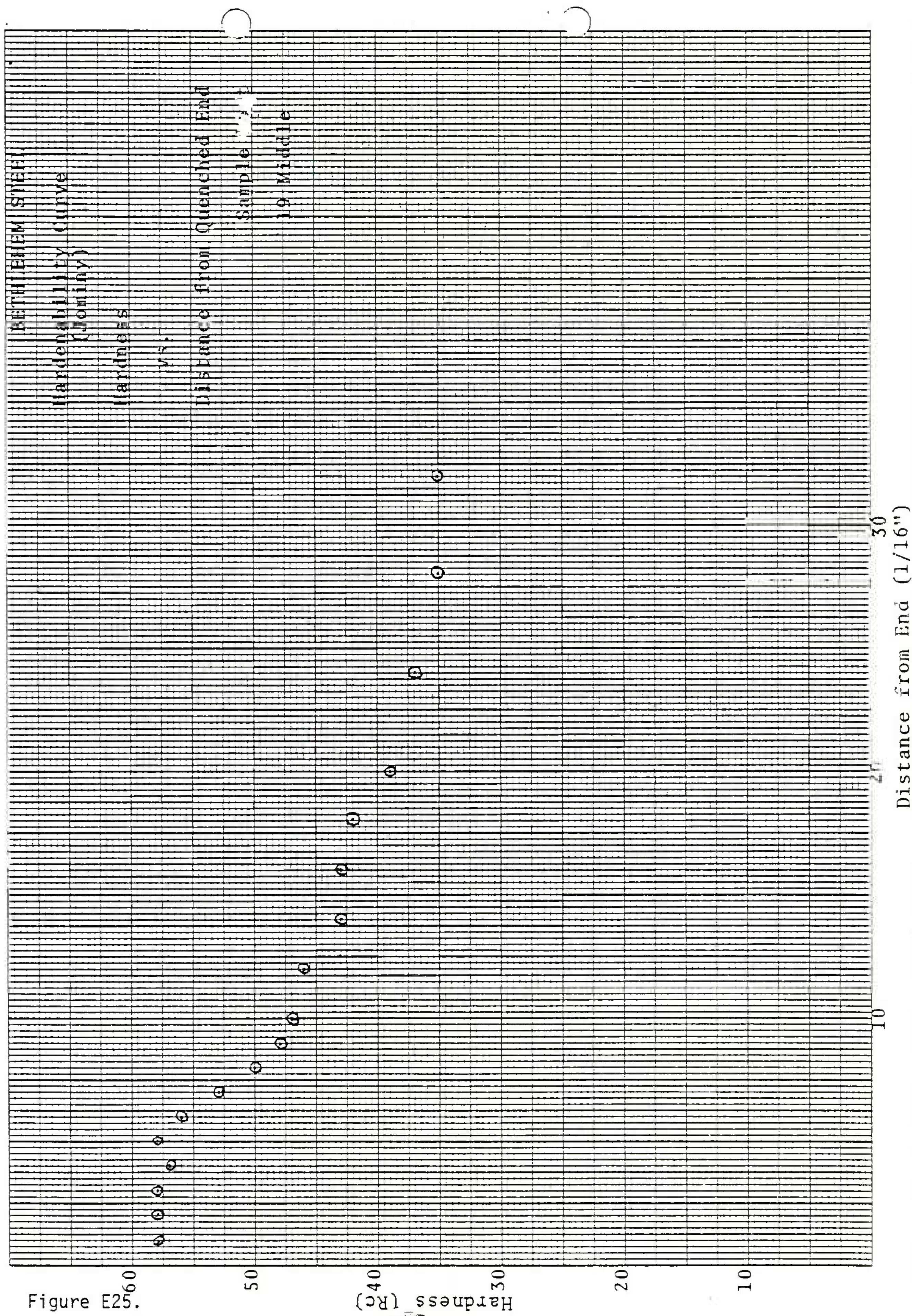
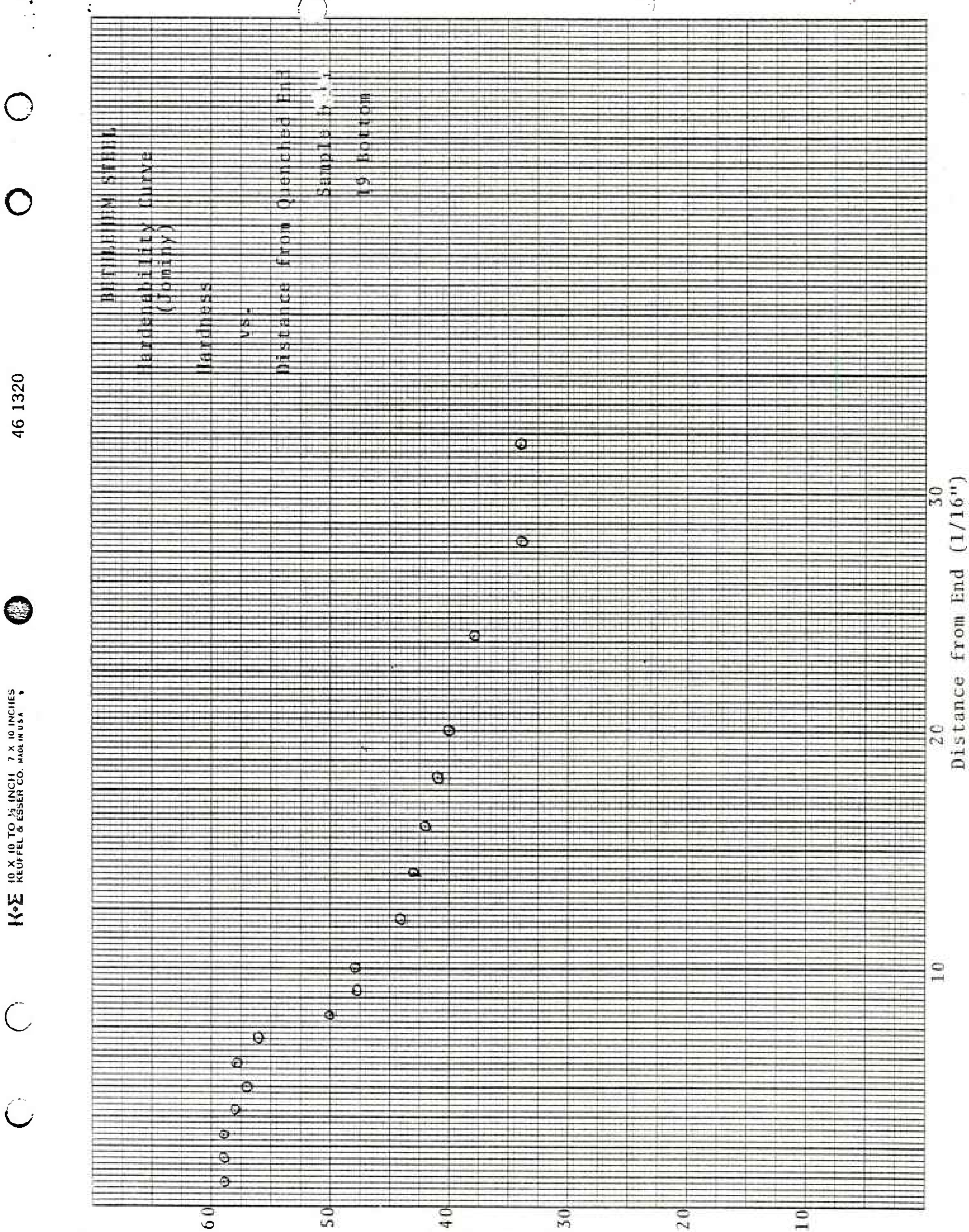

BETHLEHEM STEEL
Hardenability Curve
(Jominy)
Hardness
vs.
Distance from Quenched End
Sample
19 Middle
10
20
30
Distance from End (1/16")
60
50
40
30
20
10
Hardness (Rc)

Figure E25.



K+E 10 X 10 TO ½ INCH 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN USA
46 1320
BETHLEHEM STEEL
Hardenability Curve
(Jominy)
Hardness
vs.
Distance from Quenched End
19 Bottom
10
20
30
Distance from End (1/16")
60
50
40
30
20
10
Hardness (Rc)

Figure E26.

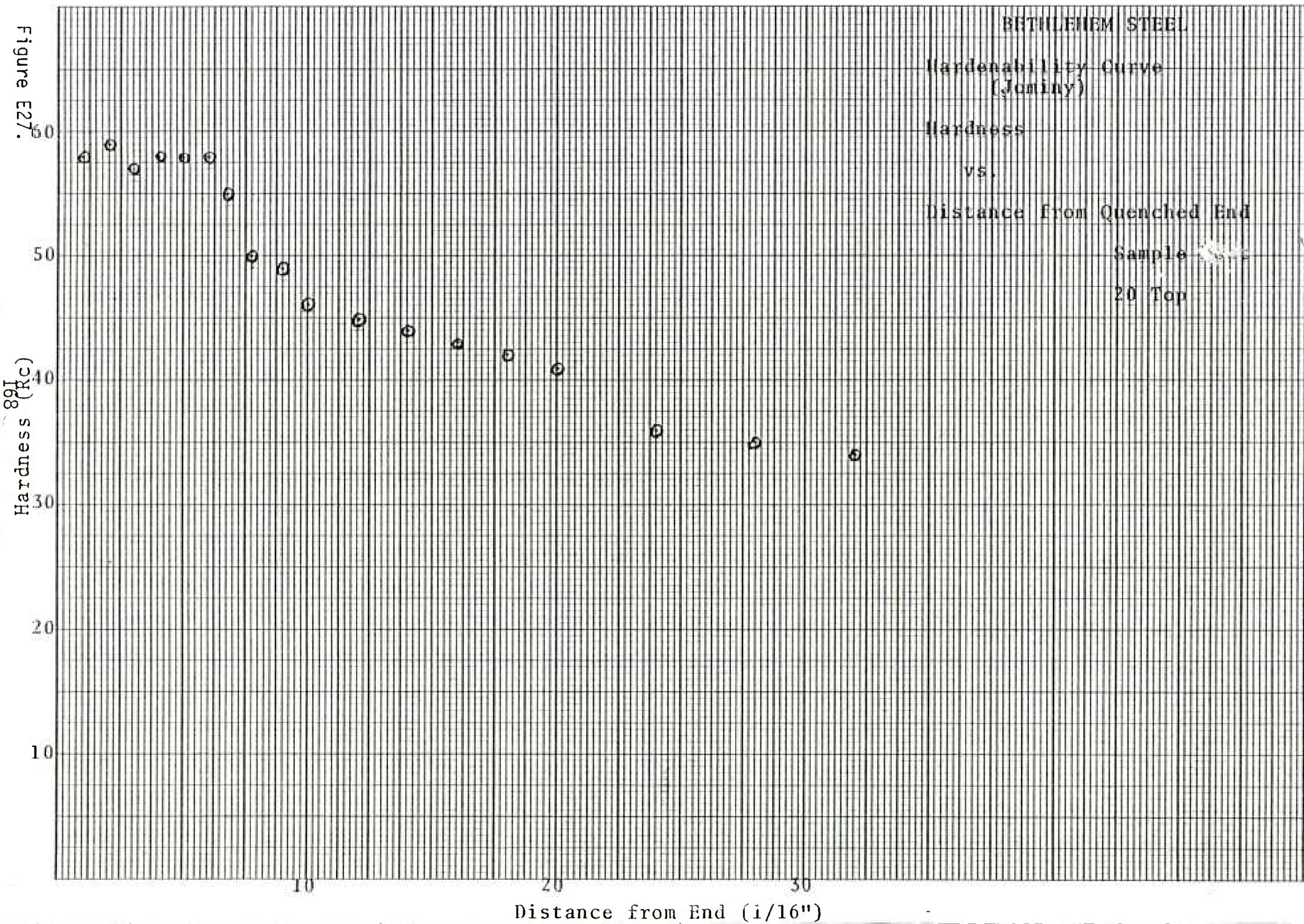

BETHLEHEM STEEL
Hardenability Curve (Jominy)
Hardness
vs.
Distance from Quenched End
Sample
20 Top
60
50
40
30
20
10
Hardness (Rc)
10
20
30
Distance from End (i/16")

Figure E27.

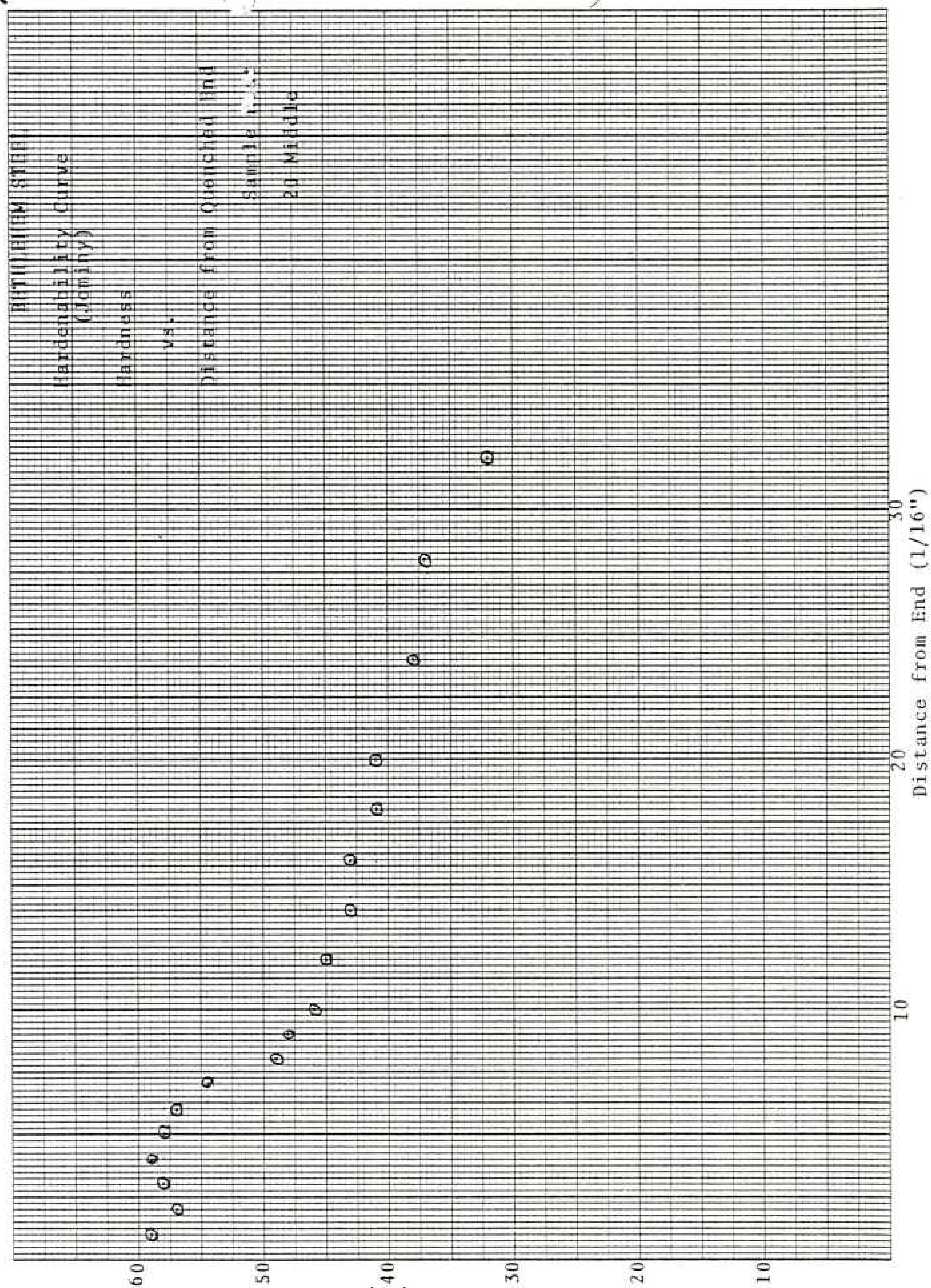

BETHLEHEM STEEL
Hardenability Curve
(Jominy)
Hardness
vs.
Distance from Quenched End
Sample
20 Middle
10
20
30
Distance from End (1/16")
60
50
40
30
20
10
Hardness (Rc)

Figure E28.

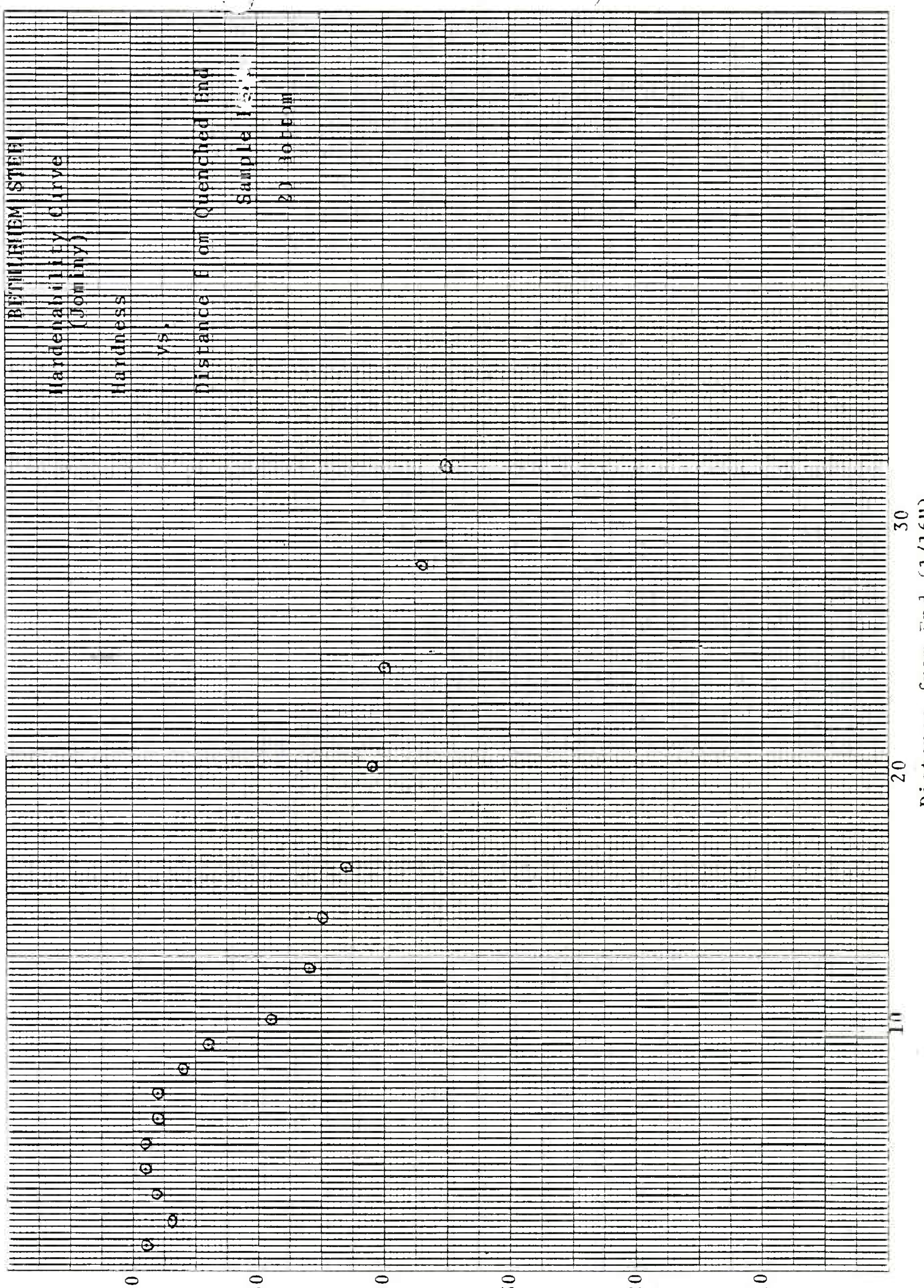

BETHLEHEM STEEL
Hardenability Curve (Jominy)
Hardness vs. Distance From Quenched End
Sample
60
50
40
30
20
10
Hardness (Rc)
10
20
30
Distance from End (1/16")

Figure E29.

Appendix F

Billet Cross Section Hardness Pattern

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

Calibration
63.1 ± 0.5
@ K 63.5

33.8	32.5	31.5	30.9	30.5	29.6	30.0	29.8	31.4	32.6
33.4	31.5	31.9	30.9	31.1	31.1	30.5	29.8	30.6	32.7
33.6	32.3	32.1	32.3	32.2	32.1	31.7	30.6	30.6	31.4
33.0	32.0	32.2	32.8	32.8	32.3	32.4	31.1	30.8	31.5
32.4	32.8	33.1	33.0	32.5	32.6	32.6	31.5	30.7	31.4
32.5	32.7	32.9	33.4	33.0	33.1	32.6	31.6	30.9	32.0
33.2	33.0	32.3	33.4	33.3	32.8	32.8	31.7	31.9	32.2
33.3	33.5	33.3	33.2	32.7	32.8	32.1	32.6	32.5	32.5
34.1	33.5	33.6	33.3	33.4	33.3	33.2	33.3	32.6	33.2
34.4	33.9	34.1	33.6	33.8	33.7	33.7	33.8	33.7	34.0

Mean 32.409

Standard Dev. 1.094

Figure F1.

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain

Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET 5¼ X 5¼ 1AA

DRN. L J F	DATE 5 22 81	SCALE FULL
CKD.		
APPD.		

Calibration
56.2 ± 1.0
56.9

REVISIONS

SYM.	DESCRIPTION	BY	DATE	APPR.

37.4	36.4	36.1	35.7	35.2	34.7	34.3	34.5	34.8	33.8
37.1	35.9	35.2	34.8	34.9	34.3	34.0	34.1	33.4	32.8
35.3	35.6	34.6	34.6	34.8	33.8	33.2	33.0	32.9	32.4
34.3	34.6	34.1	34.4	34.4	33.6	33.3	32.5	32.1	31.6
32.8	34.2	34.1	33.5	33.6	32.7	32.6	32.1	31.1	30.5
31.1	33.4	33.6	33.5	33.1	33.2	32.0	31.5	30.7	30.5
30.6	32.8	32.7	32.6	32.6	31.9	32.1	31.3	30.7	30.6
33.0	33.0	32.3	31.5	31.3	31.2	31.0	31.0	30.6	30.7
33.3	32.7	31.9	31.4	30.9	30.8	30.5	30.5	30.5	30.1
33.8	33.0	32.3	31.2	30.4	30.0	29.9	30.0	30.4	30.1

1BA

Mean 32.805

Standard Dev. 1.770

Figure F2.

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain

Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET 5¼ X 5¼ 1BA

DRN. L J F DATE 5 22 81 SCALE FULL

CKD.

APPD.

Calibrated
33.2 ± 1.0
33.4

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

38.7	39.8	39.0	38.8	38.5	38.8	38.8	37.6	37.2	36.9
39.5	39.8	38.9	38.5	38.4	39.5	39.5	38.3	37.5	36.6
39.9	39.5	39.0	38.7	38.4	38.6	38.7	38.9	38.8	37.5
40.0	40.0	39.1	38.8	38.5	38.3	39.0	38.6	38.9	37.7
40.1	39.4	39.3	38.8	38.4	38.4	38.2	39.1	39.1	38.5
40.0	39.5	39.0	38.7	38.7	38.3	38.3	38.2	39.5	39.2
39.7	39.7	39.2	38.6	38.4	39.0	38.5	38.3	39.3	39.4
39.6	39.4	39.2	38.5	38.5	38.7	38.9	38.7	38.2	39.0
39.8	39.6	38.8	38.5	38.7	38.7	38.6	38.1	38.1	37.5
40.1	39.6	39.4	39.2	39.0	38.8	38.4	38.7	37.3	38.0

1BD

Mean 38.80

Standard Dev. 0.700

Figure F3.

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain

Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE	BILLET 5¼ x 5¼ 1BD		
DRN. L J F	DATE 5 22 81	SCALE FULL	
CKD.			
APPD.			

Calibration
56.2 ± 1.0
55.6

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

29.8	29.9	29.9	31.9	30.2	31.5	31.3	33.0	33.9	33.4
29.5	30.4	32.6	33.0	32.2	32.0	32.4	32.2	33.5	34.2
30.5	30.9	33.6	33.8	33.0	32.0	34.0	34.6	33.5	35.0
30.2	33.6	33.5	32.9	32.0	34.0	33.0	33.0	33.7	34.1
31.0	33.7	32.3	35.0	33.2	34.8	34.6	33.4	33.8	36.0
31.1	30.6	34.0	33.9	33.7	35.5	35.4	35.5	33.8	36.1
33.4	34.2	35.1	35.0	34.8	35.0	36.0	34.0	33.7	35.9
33.7	34.5	33.0	33.0	35.0	33.4	35.8	36.2	34.1	35.2
34.0	34.0	32.9	35.0	33.0	33.4	36.0	34.2	34.5	34.7
36.1	35.6	36.0	35.7	33.7	35.9	34.0	34.6	35.1	35.0

20AA

Mean 33.575

Standard Dev. 1.659

Figure F4.

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain

Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET $5\frac{1}{4}$ X $5\frac{1}{4}$ 20AA		
DRN. L J F	DATE 5 22 81	SCALE FULL
CKD.		
APPD.		

Calibration
56.2 ± 1.0
56.5

REVISIONS

SYM.	DESCRIPTION	BY	DATE	APPR.

20BD

38.0	38.5	37.9	39.5	39.1	39.3	39.2	38.9	39.6	39.9
37.0	37.8	37.5	39.0	38.9	38.6	38.6	38.5	39.2	39.6
37.3	37.7	37.7	38.4	38.7	37.8	38.3	38.3	38.4	39.2
37.2	37.0	36.5	37.8	38.7	35.7	38.2	38.1	38.5	39.0
36.9	36.9	36.4	36.9	37.6	37.8	37.3	38.2	38.5	39.4
37.0	36.5	36.0	36.0	37.4	37.5	37.8	38.0	37.7	39.3
36.7	36.3	36.2	35.8	37.3	37.8	37.5	38.0	38.2	39.3
36.8	36.2	36.4	36.3	37.6	37.5	37.7	38.0	38.0	39.0
36.9	37.0	36.5	36.4	37.7	38.0	38.0	38.2	38.2	39.6
37.5	37.7	37.5	37.2	38.8	38.6	39.0	39.5	39.9	39.0

Mean Rc 37.892

Standard Dev. 1.020

Figure F5.

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain
Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET 5¼ X 5¼ 20BD		
DRN. LJF	DATE 5 22 81	SCALE FULL
CKD.		
APPD.		

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

Calibration
56.2 ± 1.0
55.8

29.5	30.4	30.0	30.5	30.7	30.8	30.6	31.9	32.9	33.2
30.6	30.8	30.7	31.3	31.5	31.3	31.7	32.0	32.7	33.5
30.6	30.8	31.1	31.7	31.4	31.8	32.2	32.4	32.4	33.6
30.3	31.2	31.7	31.4	32.3	32.0	32.0	33.1	32.1	32.9
30.7	31.8	31.5	32.0	32.6	33.3	32.1	32.7	32.7	32.8
31.3	31.9	31.8	32.7	32.7	33.1	32.8	33.2	33.0	33.2
31.8	32.6	32.6	32.8	32.9	33.1	33.4	33.5	33.3	33.6
33.2	33.0	32.8	33.0	33.7	33.7	33.8	34.2	33.5	34.6
34.2	33.8	33.4	33.8	33.2	34.2	34.6	34.6	34.2	34.8
35.0	34.5	33.9	33.8	33.2	33.6	33.1	33.8	33.9	34.5

20BA

Mean 32.554

Standard Dev. 1.218

Figure F6.

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain
Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET 5¼ X 5¼ 20BA		
DRN. L J F	DATE 5 22 81	SCALE FULL
CKD.		
APPD.		

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

Calibration
56.2 ± 1.0
56.8

36.1	36.4	36.4	35.3	35.0	34.6	34.0	33.9	34.1	33.4
36.1	36.7	36.2	36.2	36.3	35.6	35.6	34.8	34.8	34.6
36.4	37.1	36.5	36.6	36.4	35.9	35.9	35.4	34.8	35.0
36.0	37.0	35.8	36.7	36.5	35.8	36.2	35.8	35.2	35.0
36.7	36.3	36.1	36.4	37.1	37.0	36.5	35.8	35.2	35.5
37.0	36.6	36.3	35.5	36.5	37.0	36.2	35.8	35.0	35.3
36.4	36.0	35.7	35.5	35.5	35.6	35.6	35.4	35.1	35.3
36.1	35.9	35.8	35.3	35.3	35.1	35.8	36.0	35.6	35.5
37.1	36.3	35.7	34.9	35.5	35.3	35.3	35.5	35.3	35.2
36.6	36.6	35.5	34.9	34.5	34.5	34.5	34.6	33.9	35.4

40AA

Mean 35.692

Standard Dev. 0.792

Figure F7.

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain

Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET 5¼ X 5¼ 40AA		
DRN. L J F	DATE 5 22 81	SCALE FULL
CKD.		
APPD.		

Calibration
56.2 ± 1.0
55.6

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

32.5	32.3	30.9	30.1	29.5	29.3	29.1	29.2	28.7	29.1
32.6	31.7	30.6	30.2	30.0	29.4	29.1	29.2	28.8	29.2
32.3	31.4	30.4	29.8	29.5	29.7	30.0	28.3	28.9	29.1
31.5	31.0	30.1	29.6	29.9	29.6	29.4	29.5	29.6	28.8
31.5	31.0	30.1	29.6	29.9	29.6	29.4	29.5	29.6	28.8
30.6	30.0	29.8	29.9	29.8	29.4	29.7	29.5	29.2	29.0
29.8	29.5	29.9	29.7	29.5	29.6	29.5	29.7	29.0	29.1
29.8	29.3	29.3	30.0	29.5	29.5	29.3	29.5	29.3	29.5
29.2	29.3	29.3	29.3	28.9	28.7	29.5	29.3	29.3	29.7
29.2	28.9	29.4	29.0	28.8	28.5	28.7	29.4	29.3	29.2

40BA

Mean 29.696

Standard Dev. 0.830

Figure F8.

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain

Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET 5¼ X 5¼ 40BA		
DRN. L J F	DATE 5 22 81	SCALE FULL
CKD.		
APPD.		

Calibration
35.0 ± 1.0
34.6
35.0

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

36.2	36.0	35.5	33.9	34.1	34.0	34.8	35.1	35.6	35.3
37.0	35.0	34.8	34.6	34.8	35.0	35.1	34.4	34.3	35.5
36.8	34.8	35.2	35.4	34.8	35.3	35.5	35.4	34.8	35.4
35.6	35.6	35.5	34.7	35.3	35.1	35.6	36.2	35.9	35.4
35.3	36.2	36.1	35.5	35.3	35.5	35.9	35.9	35.9	35.1
35.7	35.9	36.2	35.6	35.1	35.7	36.1	36.6	36.3	35.4
36.1	36.8	36.6	36.1	35.5	35.8	36.1	36.3	36.3	35.5
36.0	36.1	36.2	35.5	35.7	35.7	36.3	36.7	36.3	35.5
36.1	36.7	36.5	36.6	37.0	36.3	35.6	36.2	36.1	36.3
36.4	36.1	36.4	36.6	36.1	36.6	35.8	35.5	35.8	37.4

40BD

Mean Rc 35.728

Standard Dev. 0.688

Figure F9.

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain

Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET		
DRN. L J F	DATE 5 22 81	SCALE FULL
CKD.		
APPD.		

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

Calibration
Rc 35.0 ± 1.0

Calibrated 6-13-80
35.1

31.0	30.9	30.6	30.8	30.7	30.5	30.1	31.0	31.2	32.1
31.4	32.1	32.0	31.9	31.8	31.9	36.3	36.4	31.9	32.0
32.5	32.7	32.4	31.9	32.4	32.7	32.2	32.5	33.0	32.0
32.8	32.9	32.6	32.3	33.5	32.6	32.4	32.5	32.4	33.0
32.8	33.2	33.0	33.1	33.6	33.1	32.7	33.0	33.9	33.4
33.5	33.4	33.6	34.1	33.7	33.2	33.4	33.3	33.5	33.7
33.3	33.8	33.4	33.1	34.0	33.2	33.4	33.5	34.2	33.8
33.0	34.0	34.5	34.7	34.1	33.3	33.9	34.1	34.6	33.0
32.6	33.7	34.1	34.0	34.1	34.6	34.5	34.0	33.4	32.9
32.3	33.3	33.4	33.1	33.0	33.2	33.5	33.3	33.0	32.8

1T

Mean 32.888
Standard Dev. 1.003

Figure F10

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain

Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET		
DRN. L J F	DATE 5 22 81	SCALE FULL
CKD.		
APPD.		

REVISIONS

SYM.	DESCRIPTION	BY	DATE	APPR.

Calibration:
Rc 35.0 ± 1.0
Calibrated
6-12-80
34.5

29.9	30.3	30.9	30.3	29.9	29.2	29.7	30.3	30.3	31.0
30.4	30.6	20.6	30.1	29.9	30.0	29.7	29.9	30.5	30.6
30.2	31.4	30.5	30.8	30.2	30.0	29.8	29.9	29.9	31.4
30.1	31.5	30.3	30.7	30.2	30.0	29.8	30.7	30.5	31.3
30.8	30.7	30.7	30.8	30.2	30.6	29.9	30.4	30.4	30.9
30.7	31.2	30.9	30.5	30.5	30.9	30.5	30.3	30.2	30.2
31.3	31.4	30.7	30.3	30.1	30.1	30.5	31.0	30.0	30.4
31.1	31.3	30.6	30.7	30.0	29.7	29.7	29.8	30.4	30.2
30.8	31.2	30.8	30.0	29.7	29.7	29.5	30.8	30.3	30.4
29.6	30.5	30.1	30.0	29.9	30.1	29.3	29.2	30.4	30.2

1 C

Mean 30.366
Standard Dev. 0.504

Figure F11.

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain
Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET

DRN. L J F | DATE 5 22 81 | SCALE FULL
CKD.
APPD.

Calibrate
Rc 35.0 ± 1
Calibrated
35.2

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

1 X

27.5	29.4	29.5	28.7	28.5	28.5	28.4	28.2	29.2	30.2
28.2	29.0	29.9	28.2	28.6	29.1	28.5	29.6	29.9	30.6
28.3	29.3	29.0	29.1	29.6	28.5	29.1	30.4	30.0	30.3
28.2	30.0	29.6	29.3	28.5	29.7	29.1	29.9	30.1	31.3
29.4	30.1	29.4	29.0	28.8	29.5	29.4	30.3	29.7	30.0
30.4	29.0	29.6	28.4	28.9	28.7	29.0	29.4	29.6	29.5
30.0	30.3	30.0	30.1	29.1	28.9	29.0	29.5	28.0	29.9
30.2	29.6	29.8	29.8	29.0	28.7	29.7	29.7	28.7	29.7
30.6	30.1	29.5	28.8	28.7	29.0	28.5	28.7	27.6	29.9
30.8	30.1	29.6	29.0	28.1	29.0	28.2	27.5	28.7	29.4

Mean 29.302
Standard Dev. 0.737

Figure F12

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain

Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET

DRN. L J F	DATE 5 22 81	SCALE FULL
CKD.		
APPD.		

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

Calibration:
Rc 35.0 ± 1
Calibrated
34.8

30.5	30.6	31.3	30.5	31.0	31.9	32.6	32.2	32.4	32.3
30.7	30.7	31.8	31.2	31.7	30.9	32.6	31.3	31.7	31.6
29.8	31.7	32.2	31.6	32.5	31.3	31.0	31.3	31.4	31.6
30.2	31.6	31.1	31.7	32.7	32.8	30.9	31.2	31.3	31.4
30.6	31.1	31.5	32.1	32.3	32.0	32.7	31.1	31.2	30.8
30.0	30.8	31.1	31.8	31.7	32.5	31.4	31.6	31.1	30.3
29.8	30.5	30.1	30.7	31.0	31.2	31.0	30.4	30.1	30.2
29.2	31.7	30.0	30.8	30.6	30.7	30.1	29.7	29.4	28.9
28.7	28.9	29.8	30.2	29.9	30.1	32.5	31.0	29.0	29.1
28.4	29.1	29.4	29.2	29.1	28.8	28.7	28.8	29.0	28.7

2 T

Mean 30.802
Standard Dev. 1.118

Figure F13

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain
Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET		
DRN. L J F	DATE 5 22 81	SCALE FULL
CKD.		
APPD.		

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

Calibrated 6-27-80

STD Rc 35.0 ± 1
34.9

25.2	27.4	26.0	24.9	25.5	24.6	28.2	25.4	25.9	25.4
26.1	25.3	26.0	25.4	26.1	26.2	25.2	25.8	27.3	25.0
26.3	25.9	25.4	24.8	25.6	25.9	26.4	26.0	27.2	25.7
26.7	25.5	25.5	26.7	25.9	27.2	27.4	26.1	25.7	26.4
25.9	25.7	25.5	24.5	26.0	25.5	25.4	25.2	25.7	26.1
26.4	26.2	26.4	26.5	27.2	27.0	25.3	26.1	26.0	26.5
25.5	26.2	25.9	25.8	25.5	27.5	26.7	26.0	25.6	25.6
25.8	25.1	25.4	26.2	25.4	24.9	25.9	25.2	26.1	25.4
26.3	26.5	25.9	27.0	27.6	27.4	25.6	25.7	25.5	25.7
25.9	25.3	26.3	25.1	25.6	25.3	25.8	25.7	26.4	25.8

2 C

Mean 25.974
Standard Dev. 0.728

Figure F14

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain
Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET

DRN. L J F	DATE 5 22 81	SCALE FULL
CKD.		
APPD.		

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

Calibrated
C 35.0 ± 1.0
35.0

Calibrated
C26.5 ± 1.0
26.3

22.3	23.7	24.7	24.5	24.9	24.6	25.4	25.2	25.5	24.2
24.0	24.2	24.5	24.6	25.2	25.0	25.5	25.1	24.4	24.1
23.8	24.0	24.5	24.7	24.8	25.0	25.1	25.0	24.4	24.4
23.9	24.4	24.0	23.6	23.9	24.5	24.3	23.8	24.5	25.1
23.7	24.1	23.3	24.0	24.0	24.0	24.2	23.5	23.7	24.3
24.0	23.7	23.7	23.5	23.8	24.3	23.6	23.4	24.1	24.3
23.3	23.4	23.9	24.5	24.0	24.0	25.0	24.0	23.6	24.8
24.0	23.6	24.6	24.3	24.6	24.9	24.5	23.7	23.6	23.9
23.5	24.0	24.4	24.7	24.7	24.5	24.8	24.4	23.4	24.2
23.3	24.5	23.8	24.0	24.4	24.2	25.0	23.6	24.8	24.1

2 x

Mean 24.231
Standard Dev. 0.568

Figure F15

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain

Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET		
DRN. L J F	DATE 5 22 81	SCALE FULL
CKD.		
APPD.		

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

Calibrate
Rc 35.0 ± 1
6/16/80
34.4

31.1	31.3	30.6	30.6	30.0	29.5	29.6	29.5	29.8	29.1
31.0	31.4	30.7	30.7	30.9	29.9	29.7	29.9	30.0	29.5
31.0	31.5	31.5	31.1	30.5	30.5	30.5	29.9	30.5	30.1
31.1	32.2	31.3	31.0	31.0	30.9	30.3	30.3	29.5	30.2
31.6	31.7	31.5	30.9	31.7	31.1	30.5	29.8	30.2	29.8
31.5	31.8	31.0	30.8	31.0	31.7	30.7	30.2	29.9	29.7
31.7	31.8	31.3	31.4	31.3	31.1	30.2	31.1	30.3	30.1
31.1	31.5	30.7	30.9	30.9	31.3	30.4	30.0	29.7	29.4
30.7	31.3	30.7	29.6	30.4	30.7	29.7	30.0	29.2	29.0
30.5	29.6	30.5	29.5	29.7	30.5	29.8	29.5	28.9	28.6

10 - T

Mean 30.514
Standard Dev 0.768

Figure F16

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain

Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET

DRN. L J F	DATE 5 22 81	SCALE FULL
CKD.		
APPD.		

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

Calibrated
6-30-80
Rc 35.0 ± 1.0
34.7

27.4	27.7	27.7	28.2	28.2	27.7	27.8	28.7	27.9	27.4
27.6	27.7	27.9	28.2	27.7	28.5	28.7	27.2	27.9	27.6
27.7	28.0	28.2	28.0	28.5	29.0	28.5	28.2	27.4	27.7
27.2	28.2	28.0	27.8	27.7	27.4	27.3	27.9	27.8	27.9
27.0	27.4	27.6	29.3	27.7	28.5	27.3	27.2	27.1	27.0
27.0	26.6	27.4	27.7	27.5	26.8	27.7	27.6	26.8	26.9
27.8	26.9	27.9	27.5	27.8	27.3	27.1	27.5	26.[illegible]	27.0
28.0	28.0	28.4	27.3	27.4	28.3	28.1	27.0	27.3	27.4
28.2	28.0	27.5	27.5	27.5	27.8	28.5	28.4	28.5	27.9
27.8	28.7	28.7	28.4	27.6	28.1	28.5	28.0	27.3	26.9

10 - C

Mean 27.758
Standard Dev. 0.543

Figure F17

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain
Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET

DRN. L J F	DATE 5 22 81	SCALE FULL
CKD.		
APPD.		

Calibrate
Rc 35.0 ± 1

6-20-80
34.5

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

30.1	29.7	29.5	29.8	29.0	29.1	29.2	29.7	29.2	29.6
30.2	29.4	29.4	29.1	29.0	29.4	29.9	30.0	30.1	30.1
30.2	30.1	29.9	30.0	29.7	30.0	29.8	29.6	30.5	31.2
30.9	30.0	29.9	30.0	30.0	29.9	29.8	30.0	30.4	30.5
30.8	29.6	30.0	30.4	30.0	30.6	30.0	30.4	31.1	31.5
30.7	29.5	30.3	30.0	30.0	29.9	30.5	30.7	30.5	30.9
30.5	29.4	30.4	30.4	30.7	30.0	30.6	30.2	30.5	31.3
30.4	29.8	30.5	29.6	29.6	29.4	30.2	29.8	29.9	31.0
30.7	29.8	29.9	29.3	29.0	29.5	29.2	29.8	30.3	31.0
29.7	29.7	29.5	29.2	28.8	29.4	30.0	30.0	30.3	31.0

10 X

Mean 30.016
Standard Dev. 0.562

Figure F18

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain
Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET

DRN. L J F	DATE 5 22 81	SCALE FULL
CKD.		
APPD.		

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

Calibrated
6-26-80
Std. Rc 35.0 ± 1
34.5

29.2	29.0	28.4	28.6	28.0	28.6	28.3	29.7	28.0	28.7
29.0	29.0	28.9	29.4	28.0	28.7	29.0	29.6	28.5	28.4
29.7	29.8	28.6	29.5	29.4	29.1	28.4	28.9	28.8	29.1
29.4	29.1	29.0	28.9	29.4	28.9	28.1	30.0	32.0	28.5
29.7	28.3	29.0	29.9	29.9	32.6	29.6	29.2	30.0	28.3
30.0	29.9	29.4	30.0	32.2	30.2	30.7	28.4	29.4	28.9
29.0	28.7	30.3	29.9	30.1	29.6	31.0	29.2	32.0	28.7
29.5	29.5	28.7	28.4	29.1	29.4	32.4	28.9	29.9	29.0
28.4	28.6	28.7	28.3	28.3	29.4	39.2	29.3	28.9	28.1
29.0	28.7	28.2	27.6	27.9	29.5	28.6	28.7	27.8	27.6

11 T

Mean 29.195
Standard Dev. 0.960

Figure F19.

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain
Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE	BILLET			
DRN. L J F	DATE 5 22 81	SCALE FULL		
CKD.				
APPD.				

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

Calibrate
Rc 35.0 ± 1
Calibrated
35.7

29.2	30.3	30.4	30.8	30.0	29.8	29.5	30.1	29.5	29.7
28.0	30.4	30.8	30.6	30.0	30.5	30.2	30.7	30.4	30.2
28.8	30.6	29.3	30.3	31.1	30.2	30.2	30.1	30.4	30.1
28.8	29.0	29.1	29.6	30.3	29.4	29.7	28.8	29.0	29.5
28.5	29.4	28.5	28.6	28.5	29.2	29.0	29.0	28.6	28.3
28.5	28.0	28.1	28.6	28.3	28.5	28.5	29.0	28.6	28.7
28.7	27.5	28.1	28.0	29.0	29.1	28.0	28.5	28.4	28.5
27.8	27.3	28.6	28.4	28.3	28.5	28.2	27.9	28.0	28.0
29.0	29.2	29.4	28.9	29.1	29.2	29.0	29.5	30.0	29.4
29.9	29.8	30.3	29.9	29.9	29.8	30.8	30.5	30.1	29.3

11 C

Mean 29.282
Standard Dev. 0.866

Figure F20

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain
Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET

DRN. L J F	DATE 5 22 81	SCALE FULL
CKD.		
APPD.		

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

Calibrate
Rc 35.0 ± 1.0
Calibrated 6-9-80
34.7

28.6	30.0	30.6	30.0	30.3	30.6	29.5	30.7	29.9	30.2
29.2	30.1	30.5	29.7	30.0	30.2	29.7	30.7	30.0	29.8
29.5	29.7	29.7	29.5	30.3	29.5	29.0	29.2	28.5	29.0
29.9	29.0	30.3	29.0	29.9	29.2	29.5	28.9	29.0	29.1
30.4	30.2	30.1	29.5	29.6	30.5	29.7	29.2	29.2	30.1
30.2	31.1	30.4	30.0	30.2	29.9	29.5	28.8	29.0	29.7
30.1	30.9	30.4	30.3	30.1	30.8	30.0	30.1	30.0	29.2
30.1	30.6	30.6	30.4	30.9	30.5	31.0	30.6	29.9	30.0
30.5	30.7	31.4	31.8	31.3	30.9	31.0	31.0	30.9	29.8
29.7	30.1	31.5	31.5	31.6	31.4	31.6	31.2	30.6	30.0

11 X

Mean 30.103
Standard Dev. 0.728

Figure F21

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain

Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET		
DRN. L J F	DATE 5 22 81	SCALE FULL
CKD.		
APPD.		

Calibrate
Rc 35.0 ± 1
Calibrated
35.2

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

27.5	29.2	28.6	28.8	30.1	29.5	29.0	29.5	28.6	29.1
30.1	29.4	29.9	30.1	29.8	29.9	30.0	29.9	29.9	29.7
29.7	29.9	30.0	30.2	30.8	30.3	30.2	30.0	30.0	30.3
29.9	30.9	30.5	30.7	31.2	30.8	30.5	30.1	29.7	29.5
30.1	30.4	31.5	31.2	31.4	31.1	30.8	29.2	28.6	29.3
29.8	30.3	30.1	30.2	31.4	30.8	31.2	31.0	29.0	28.3
29.4	30.0	30.8	30.0	30.0	30.0	29.9	30.5	29.2	28.6
29.2	29.4	28.9	30.0	30.0	30.0	30.0	29.9	29.8	29.9
29.1	28.0	31.0	30.2	31.0	31.3	30.2	29.9	28.9	29.9
28.1	29.5	28.7	30.0	30.0	30.1	29.9	29.7		

19 T

Mean 29.893
Standard Dev. 0.775

Figure F22

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain
Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET		
DRN. L J F	DATE 5 22 81	SCALE FULL
CKD.		
APPD.		

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

Calibrate
Rc 35.0 ± 1.0
Calibrated 6-11-80
34.8

29.1	30.7	31.1	31.5	31.1	31.0	31.1	31.6	30.3	30.8
30.8	30.6	31.1	30.9	30.4	30.2	30.2	31.3	31.0	30.5
30.4	30.5	29.9	31.5	29.5	31.2	30.5	30.6	31.0	30.2
30.1	29.4	29.9	29.8	29.5	30.6	30.5	30.4	29.7	29.2
30.2	29.3	30.1	30.3	30.4	29.9	30.1	30.1	28.5	29.2
28.8	29.5	29.2	29.3	30.2	29.4	28.6	29.1	27.2	28.6
28.1	28.4	29.9	28.9	30.5	29.2	28.7	29.2	29.0	29.6
28.8	29.5	28.8	28.0	28.8	29.8	28.9	29.2	29.9	29.2
28.8	29.3	30.2	29.8	30.6	30.0	30.2	28.8	29.8	29.0
29.8	29.9	29.6	29.1	29.5	29.0	29.5	29.2		

19 C

Mean 29.779
Standard Dev. 0.886

Figure F23

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain

Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET		
DRN. L J F	DATE 5 22 81	SCALE FULL
CKD.		
APPD.		

Calibrate
Rc 35.0 ± 1.0
Calibrated 6-11-80
34.8

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

30.0	29.7	30.1	30.8	31.2	30.7	30.7	29.6	29.7	28.9
30.4	30.5	31.0	30.6	31.3	31.6	32.3	30.8	30.3	29.4
31.3	32.0	30.7	31.2	31.8	32.7	31.0	31.2	30.2	30.4
31.3	31.9	31.1	31.4	32.4	32.0	32.3	30.9	30.7	30.5
31.6	32.0	31.2	30.9	31.4	31.7	30.9	30.3	30.9	30.8
31.0	32.0	31.1	31.3	31.8	31.8	31.4	30.7	31.1	30.3
30.5	31.3	31.1	32.0	32.0	31.7	31.3	30.8	30.7	31.1
31.4	31.4	31.2	30.9	31.1	31.2	31.4	30.6	31.0	30.5
30.4	30.7	31.1	31.2	31.3	30.6	31.1	30.6	30.4	30.2
30.8	30.0	30.5	31.1	30.4	30.5	30.2	30.2	29.8	30.1

20 - T

Mean 30.952
Standard Dev. 0.683

Figure F24

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain
Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET		
DRN. L J F	DATE 5 22 81	SCALE FULL
CKD.		
APPD.		

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

Calibrate
Rc 35.0 ± 1
Calibrated
35.2

25.7	24.7	25.0	25.4	25.6	25.2	25.5	24.9	24.7	24.8
25.2	24.9	24.4	24.5	25.0	24.4	24.3	24.8	25.2	24.2
25.6	25.2	24.6	25.7	24.7	24.0	24.4	24.2	25.1	23.8
26.5	26.0	25.1	25.2	24.5	24.1	24.7	25.4	24.9	25.5
25.4	25.8	25.4	25.6	24.4	24.3	24.0	25.3	24.9	25.5
25.5	25.5	24.9	24.5	23.6	24.6	24.8	25.2	25.6	25.7
24.7	25.1	24.0	24.7	23.5	24.3	24.4	25.0	24.3	25.5
25.7	25.3	24.4	23.1	24.5	23.9	24.4	23.7	25.1	25.5
25.2	24.6	24.0	23.7	24.2	23.8	23.8	23.5	25.6	24.5
24.3	24.1	24.2	23.7	24.2	24.3	25.2	24.8	24.8	23.3

19 X

Mean 24.748
Standard Dev. 0.669

Figure F25

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain
Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET		
DRN. L J F	DATE 5 22 81	SCALE FULL
CKD.		
APPD.		

Calibrate
Rc 35.0 ± 1.0
Calibrated 6-11-80
34.8

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

29.7	30.7	31.1	31.1	31.3	31.7	31.2	31.7	30.5	30.5
30.2	30.2	30.8	30.4	30.5	30.7	31.5	31.0	31.5	30.3
30.8	29.9	31.0	30.7	31.3	31.6	31.2	31.0	31.1	30.6
29.9	29.7	31.1	30.8	31.1	31.5	31.5	30.3	30.3	30.1
30.2	29.5	30.6	30.0	30.8	30.2	30.5	30.6	30.0	30.0
29.7	29.0	30.3	30.0	30.8	30.5	30.4	30.0	29.7	29.5
30.6	29.7	30.4	29.7	30.6	30.2	30.0	30.0	30.3	29.7
29.8	27.6	30.2	29.8	30.0	30.5	30.4	30.3	29.6	29.4
30.3	30.6	30.6	29.6	30.4	30.5	30.0	30.4	30.7	29.8
30.8	30.3	31.1	30.2	30.8	30.4	30.9	31.0	30.6	30.4

20 C

Mean 30.429
Standard Dev. 0.632

Figure F26

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain
Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE BILLET		
DRN. LJF	DATE 5 22 81	SCALE FULL
CKD.		
APPD.		

Calibrate
Rc 35.0 1 1.0
Calibrated 6-9-80
34.5

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.

30.0	30.6	30.2	29.0	29.7	29.0	30.1	29.5	29.4	29.6
30.6	29.6	29.5	30.0	29.4	29.4	29.2	29.9	29.6	29.8
31.3	30.3	30.3	29.3	29.6	30.0	28.7	29.8	30.2	30.8
31.0	31.7	30.2	30.0	29.8	29.7	29.3	30.3	30.6	30.5
30.1	31.6	30.7	30.0	30.1	29.8	30.1	30.2	30.1	31.6
30.5	31.2	30.2	30.8	29.6	30.1	30.3	29.8	30.6	31.4
30.5	31.0	30.4	29.5	29.5	29.9	30.6	30.3	29.7	31.2
31.3	30.9	30.5	29.8	29.8	29.9	29.8	29.6	30.5	30.6
30.6	30.4	29.8	29.8	30.8	30.4	29.9	28.6	30.0	30.7
29.8	30.7	30.1	30.4	30.1	31.3	30.6	30.2	30.2	31.4

20 X

Mean 30.174
Standard Dev. 0.630

Figure F27

TOLERANCES UNLESS OTHERWISE SPECIFIED		Chamberlain Chamberlain Manufacturing Corporation Scranton Army Ammunition Plant		
.000	± .005			
.00	± .010	TITLE BILLET		
.0	± .020			
FRAC.	± 1/32	DRN. L J F	DATE 5 22 81	SCALE FULL
ANGLE	± 1°	CKD.		
		APPD.		

Appendix G

Photomicrographs of Edge Cross Section

Republic Steel
Picral Etchant
63x

Figure G1.

Top Billet of
1st Ingot

Figure G2.

Middle Billet of
1st Ingot

Figure G3.

Bottom Billet of
1st Ingot

Figure G4.

Top Billet of
20th Ingot

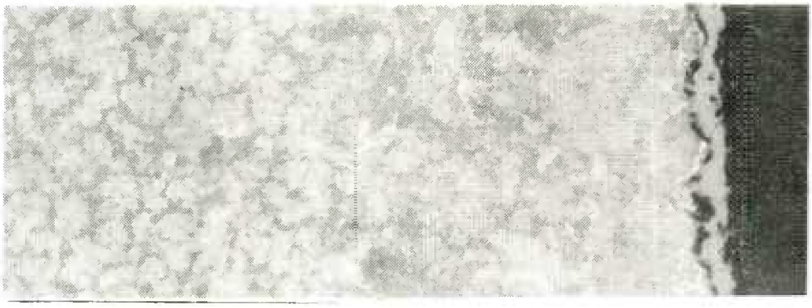


Figure G5.

Middle Billet of
20th Ingot

Republic Steel
Picral Etchant
63x

Figure G6.

Bottom Billet of 20th Ingot

Figure G7.

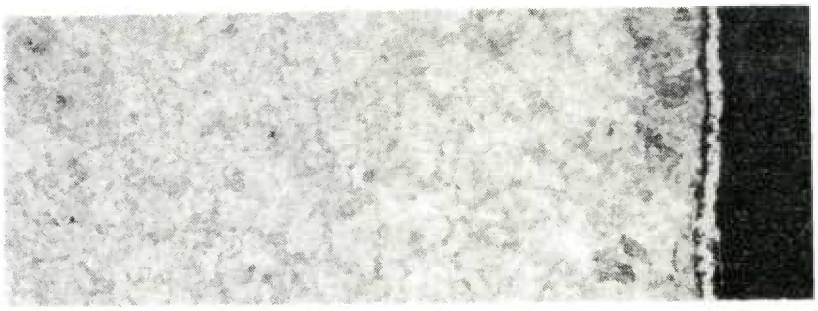
Top Billet of 40th Ingot

Figure G8.

Middle Billet of 40th Ingot

Figure G9.

Bottom Billet of 40th Ingot



Bethlehem Steel
Picral Etchant
63x

Figure G10.

1 Top

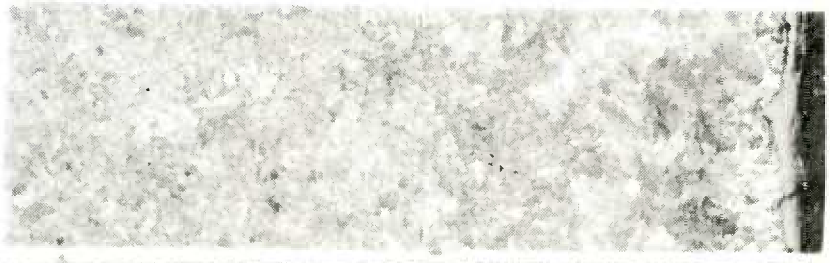


Figure G11.

1 Middle

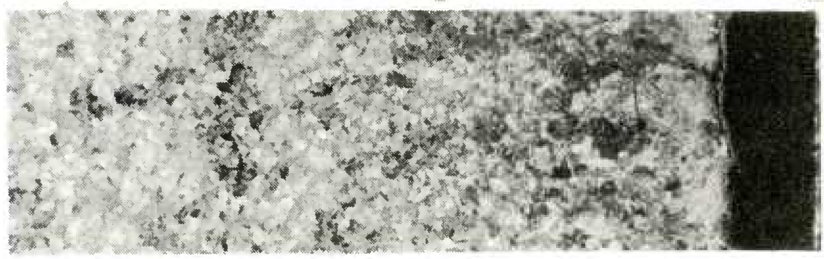


Figure G12.

1 Bottom

Figure G13.

2 Top

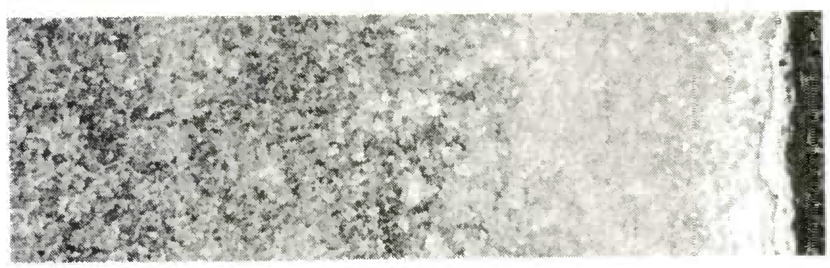


Figure G14.

2 Middle

Figure G15.

2 Bottom

Bethlehem Steel
Picral Etchant
63x

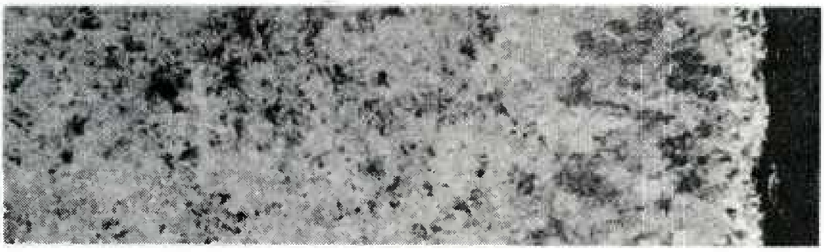


Figure G16.

10 Top

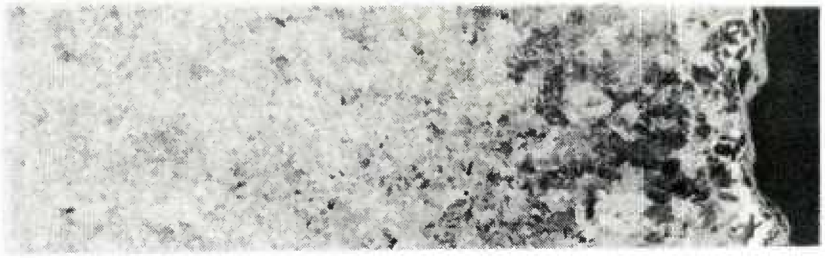


Figure G17.

10 Middle

Figure G18.

10 Bottom

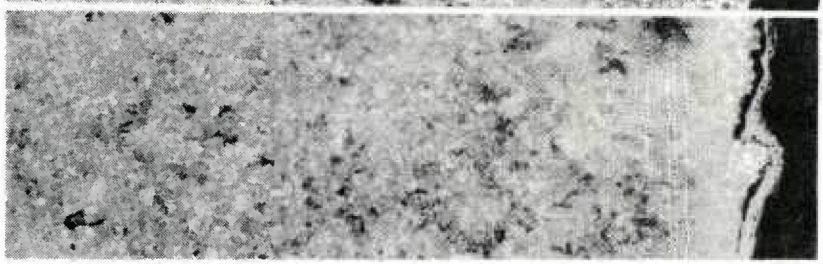


Figure G19.

11 Top

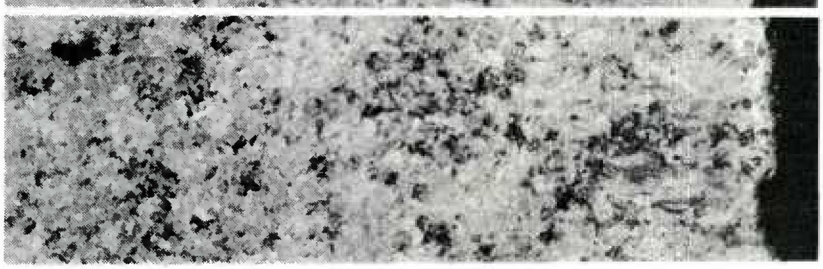


Figure G20.

11 Middle

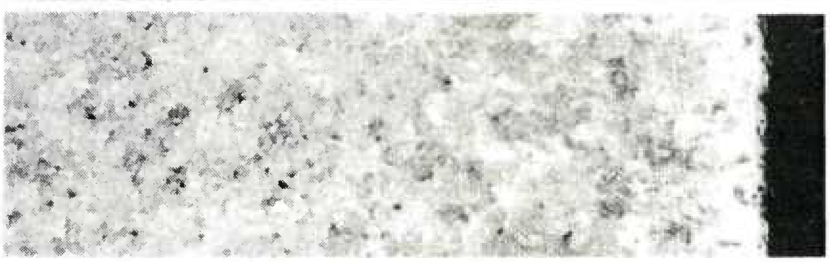


Figure G21.

11 Bottom

Bethlehem Steel
Picral Etchant
63x

Figure G22.

19 Top

Figure G23.

19 Middle

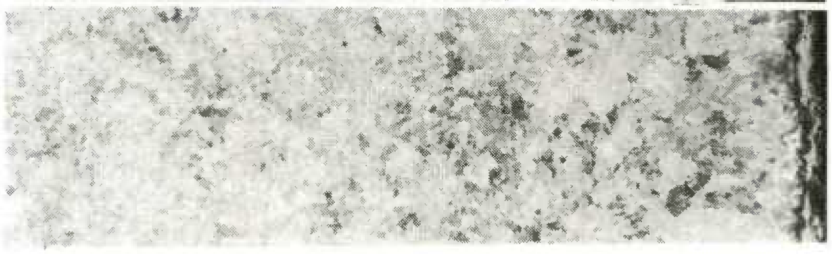


Figure G24.

19 Bottom

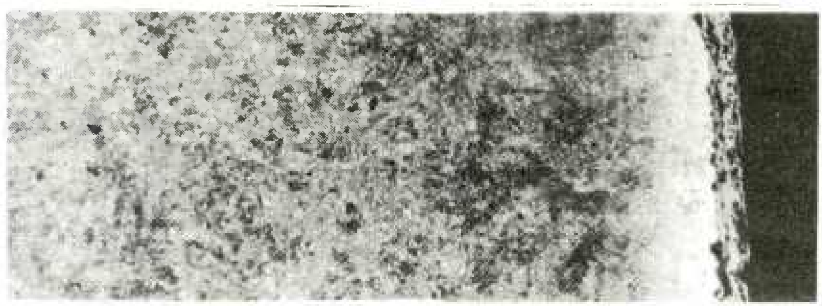


Figure G25.

20 Top

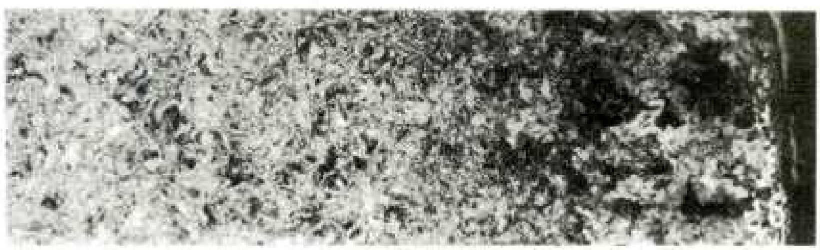


Figure G26.

20 Middle

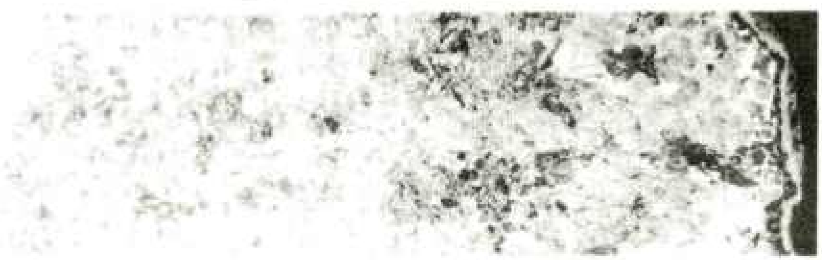
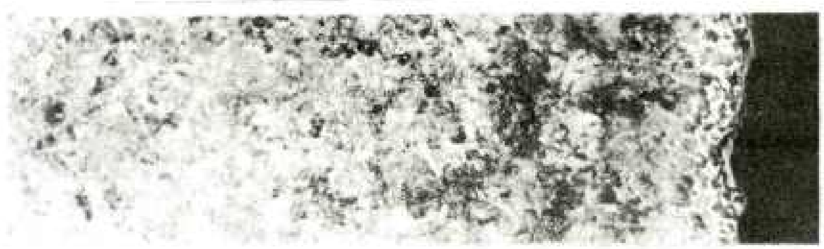


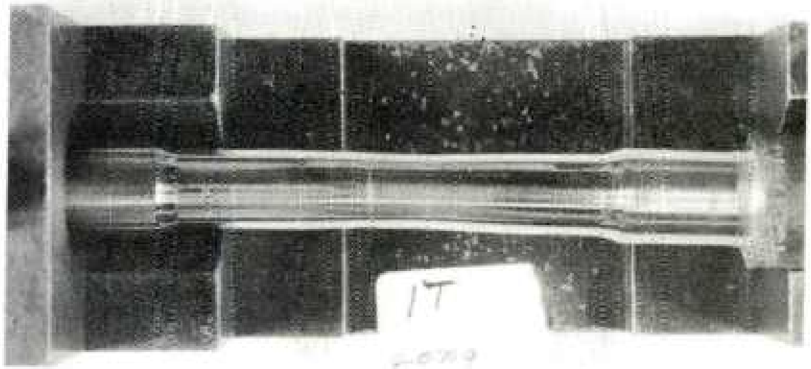
Figure G27.

20 Bottom



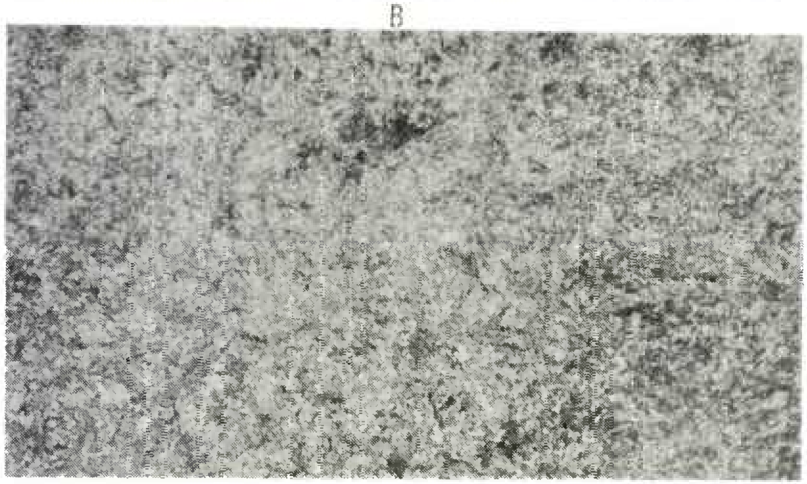
Appendix H

Photographs of Heat Treated Specimens



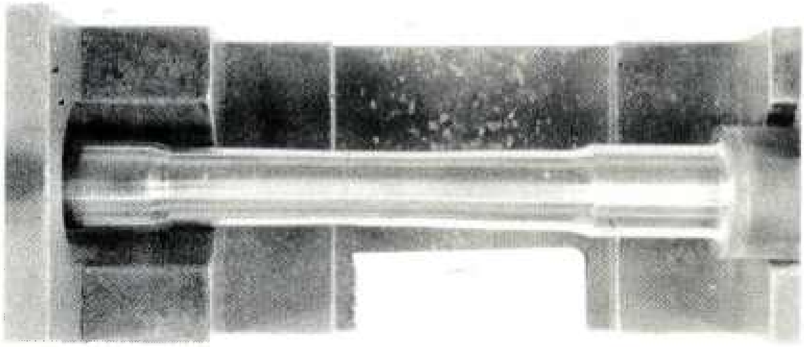
A

B

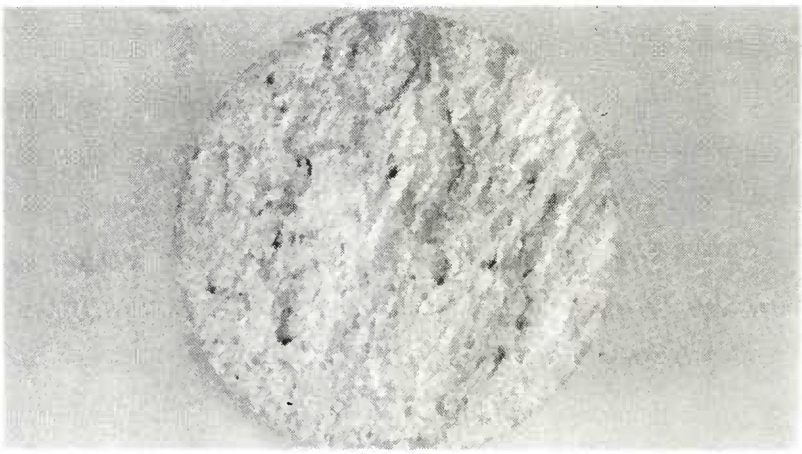


C

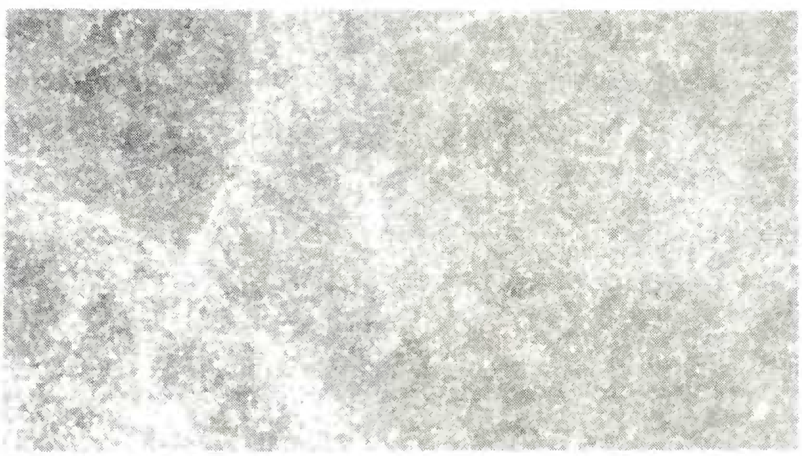
Figure H1. Bethlehem Steel Longitudinal Section of Billet 1T.
(a) Tensile Bar. 0.8x (b) Fractured Surface. 5x
(c) Heat Treatment. 500x 2% Nital.



A

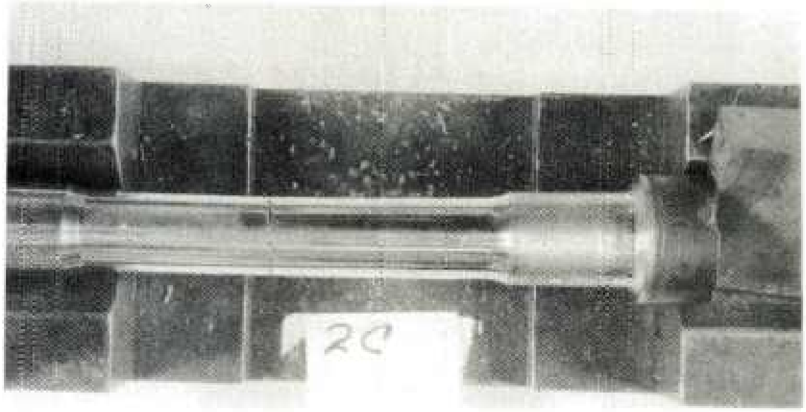


B



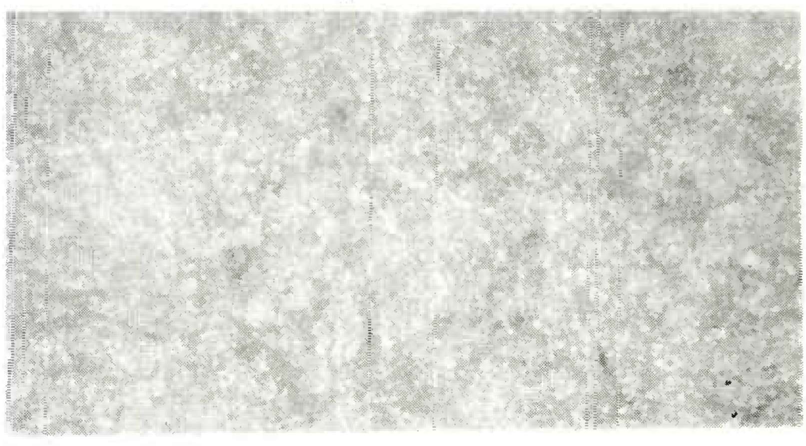
C

Figure H2. Bethlehem Steel Transverse Section of Billet 1T.
(a) Tensile Bar. 0.8x (b) Fractured Surface. 5x
(c) Heat Treatment. 500x 2% Nital.



A

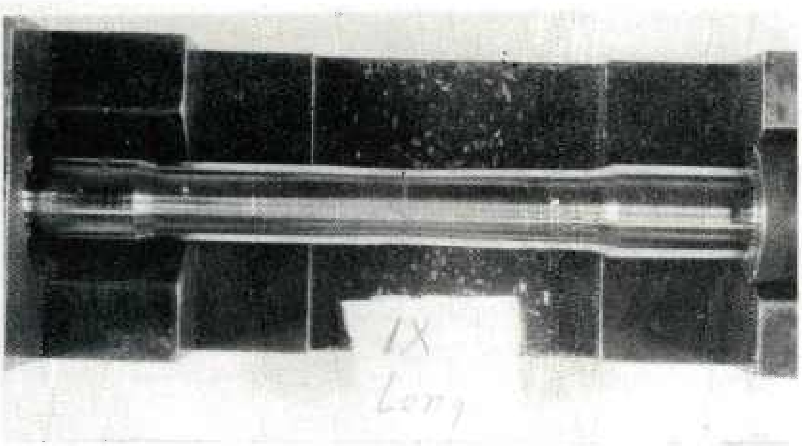
B



C

Figure H3. Bethlehem Steel Transverse Section of Billet 20.
(a) Tensile Bar. 0.8x (b) Fractured Surface. 5x
(c) Heat Treatment. 500x 2% Nital.

BETHLEHEM STEEL



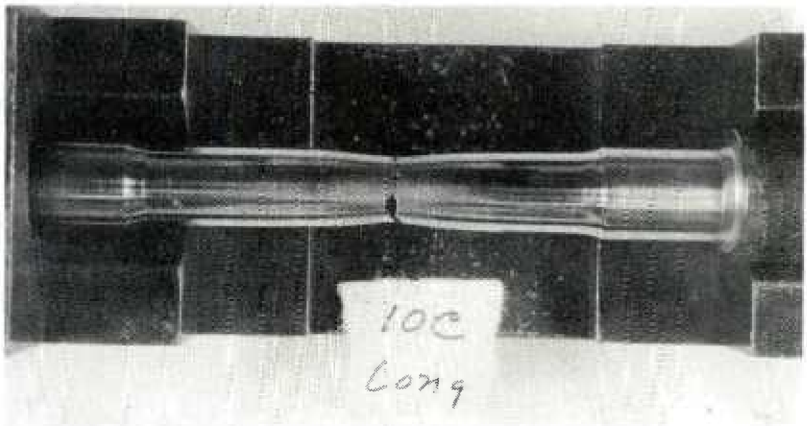
A

B

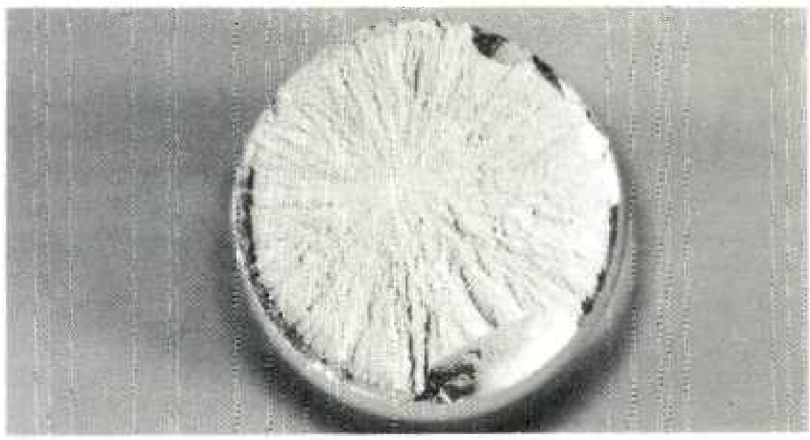
C

Figure H4. Bethlehem Steel Longitudinal Section of Billet 1X.
(a) Tensile Bar. 0.8x (b) Fractured Surface. 5x
(c) Heat Treatment. 500x 2% Nital

BETHLEHEM STEEL



A

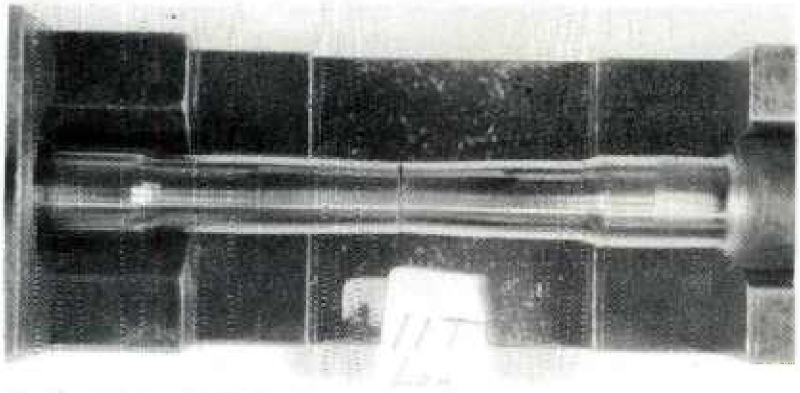


B

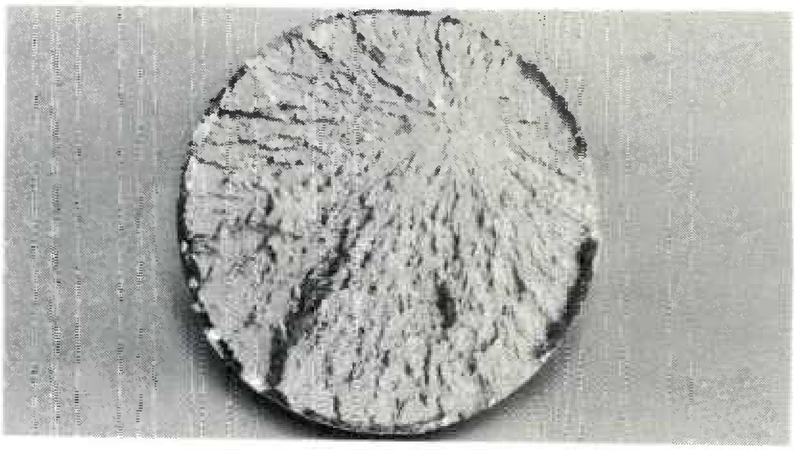
C

Figure H5. Bethlehem Steel Longitudinal Section of Billet 10C.
(a) Tensile Bar. 0.8x (b) Fractured Surface. 5x
(c) Heat Treatment. 500x 2% Nital.

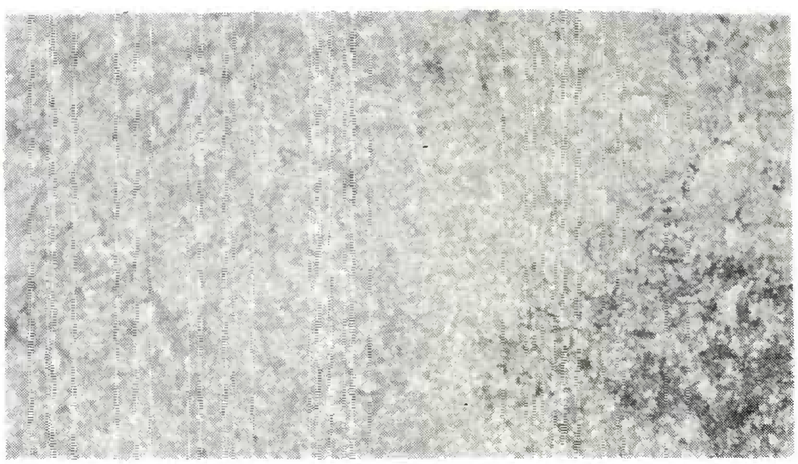
BETHLEHEM STEEL



A

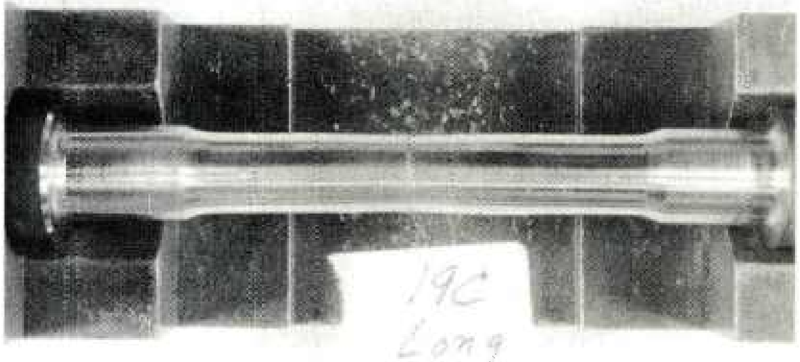


B



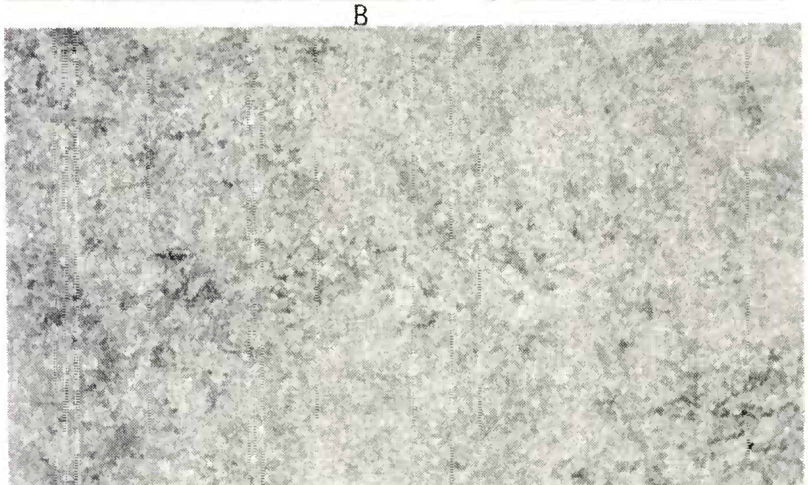
C

Figure H6. Bethlehem Steel Longitudinal Section of Billet 11T.
(a) Tensile Bar. 0.8x (b) Fractured Surface. 5x
(c) Heat Treatment. 500x 2% Nital.



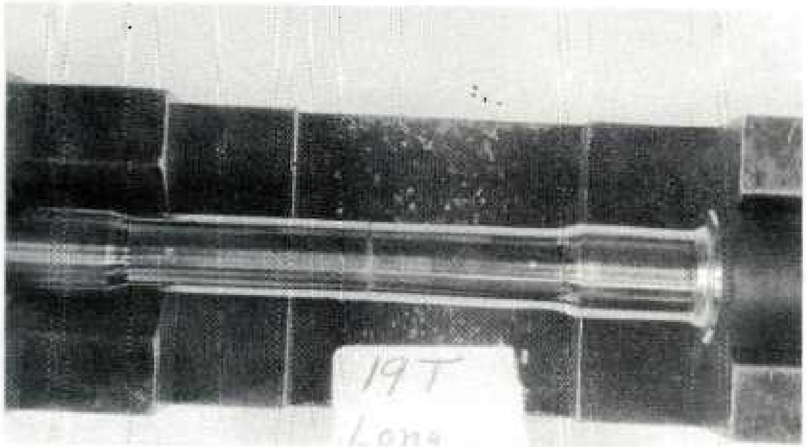
A

B



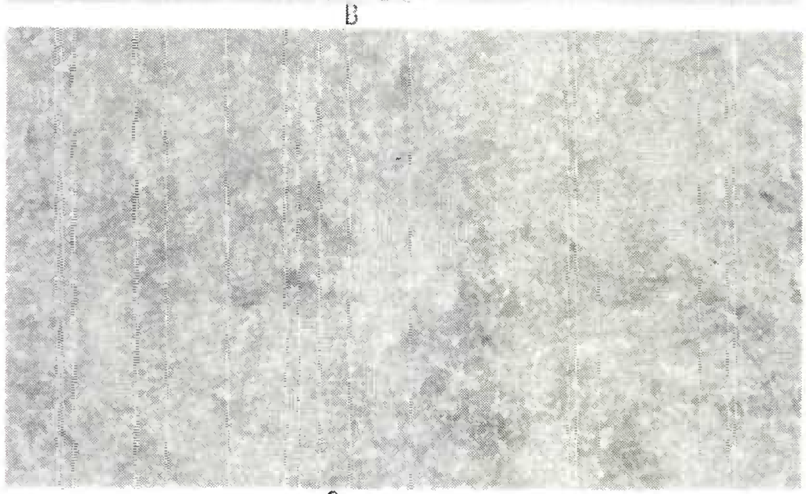
C

Figure H7. Bethlehem Steel Longitudinal Section of Billet 19C.
(a) Tensile Bar. 0.8x (b) Fractured Surface. 5x
(c) Heat Treatment. 500x 2% Nital.



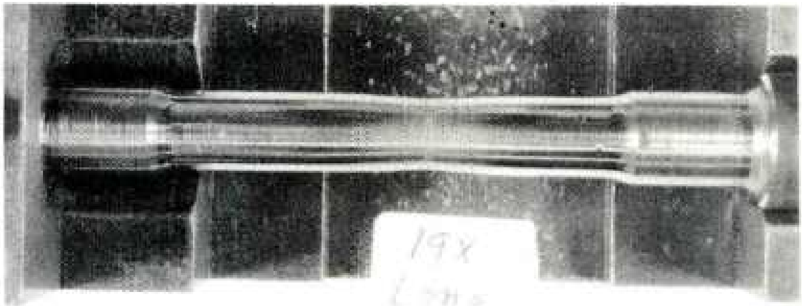
A

B



C

Figure H8. Bethlehem Steel Longitudinal Section of Billet 19T.
(a) Tensile Bar. 0.8x (b) Fractured Surface. 5x
(c) Heat Treatment. 500x 2% Nital.

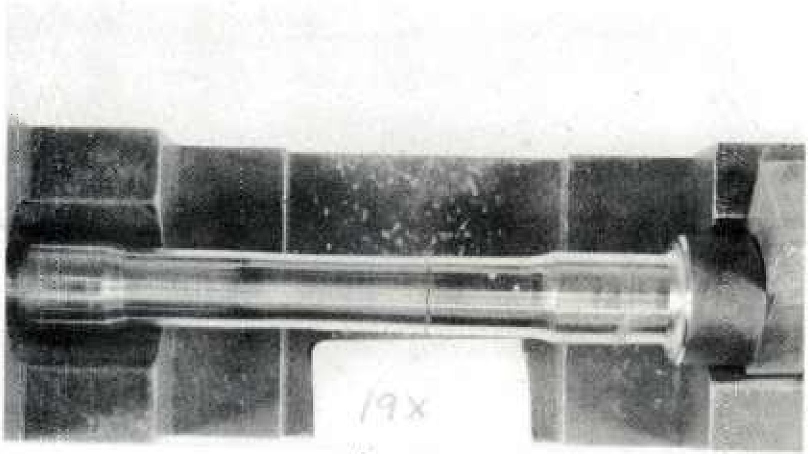


A

B

C

Figure H9. Bethlehem Steel Longitudinal Section of Billet 19X.
(a) Tensile Bar. 0.8x (b) Fractured Surface. 5x
(c) Heat Treatment. 500x 2% Nital.

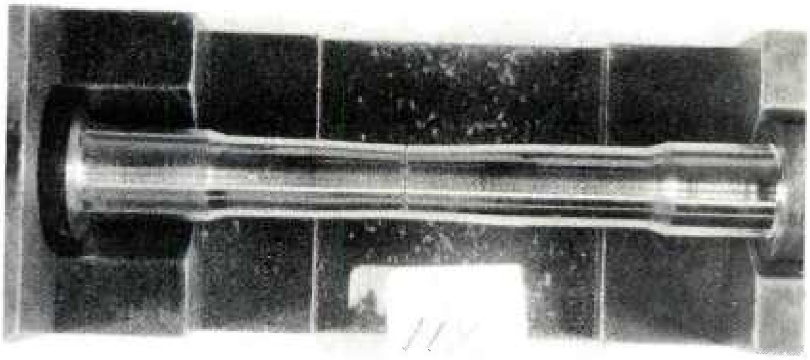


A

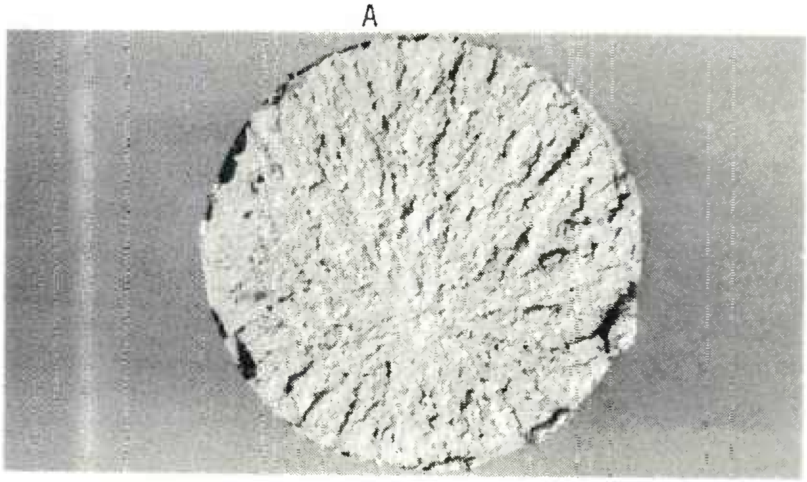
B

C

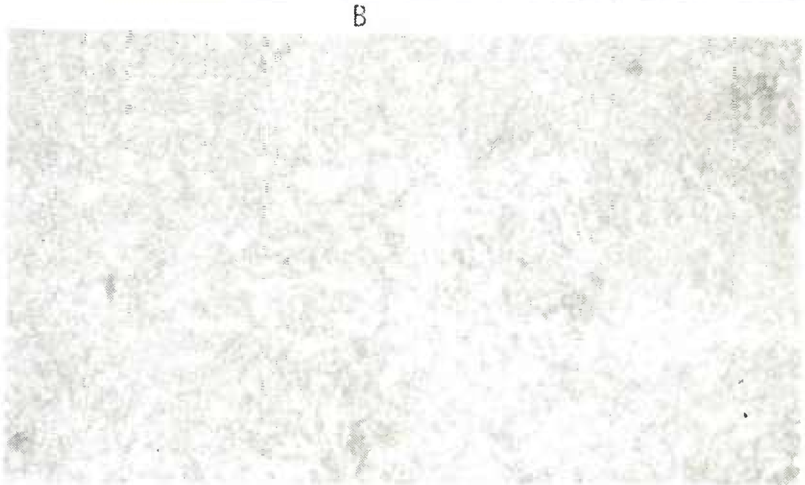
Figure H10. Bethlehem Steel Transverse Section of Billet 19X.
(a) Tensile Bar. 0.8x (b) Fractured Surface. 5x
(c) Heat Treatment. 500x 2% Nital.



A

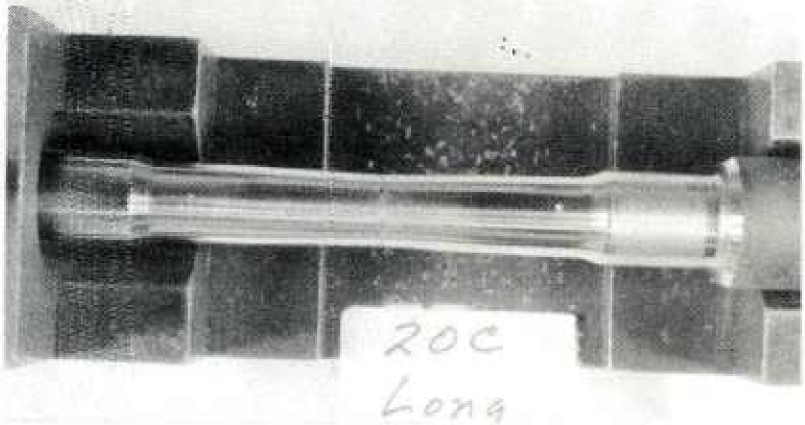


B

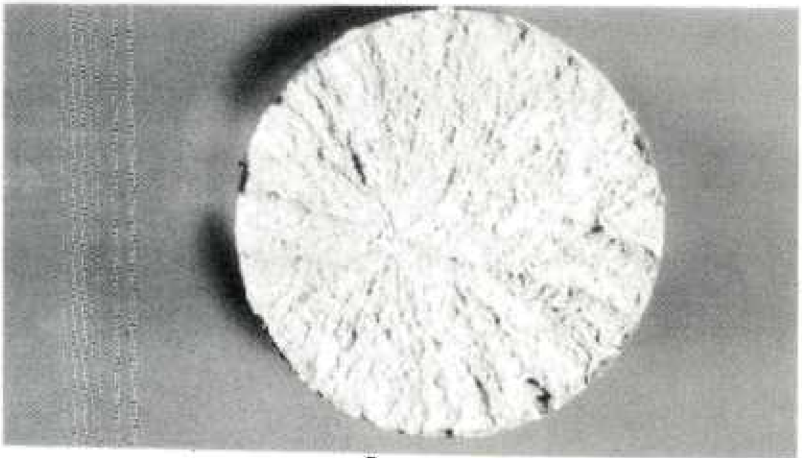


C

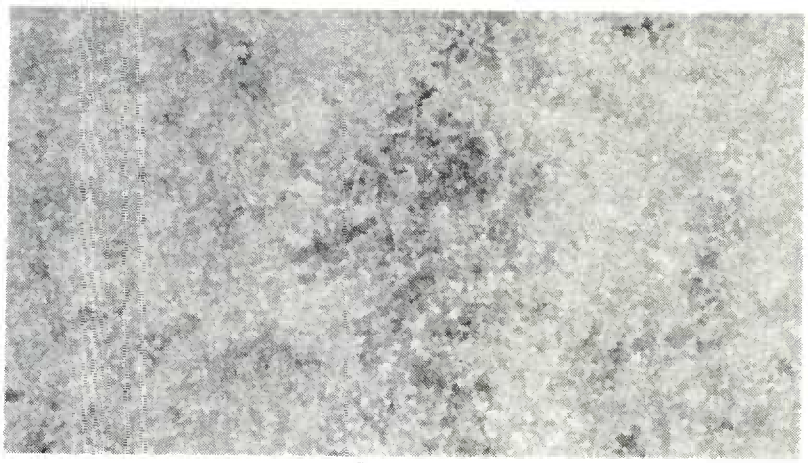
Figure H11. Bethlehem Steel Longitudinal Section of Billet 11X.
(a) Tensile Bar. 0.8x (b) Fractured Surface. 5x
(c) Heat Treatment. 500x 2% Nital.



A



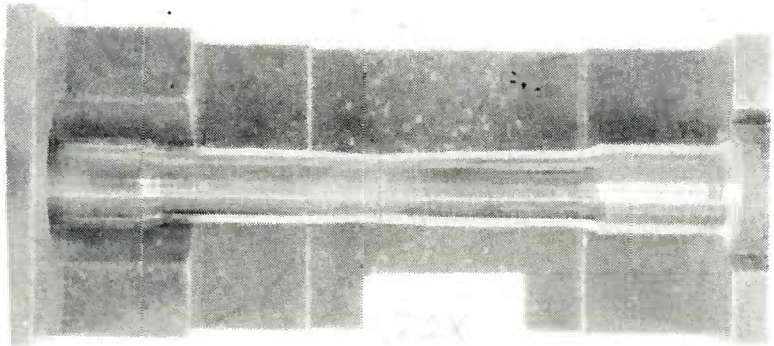
B



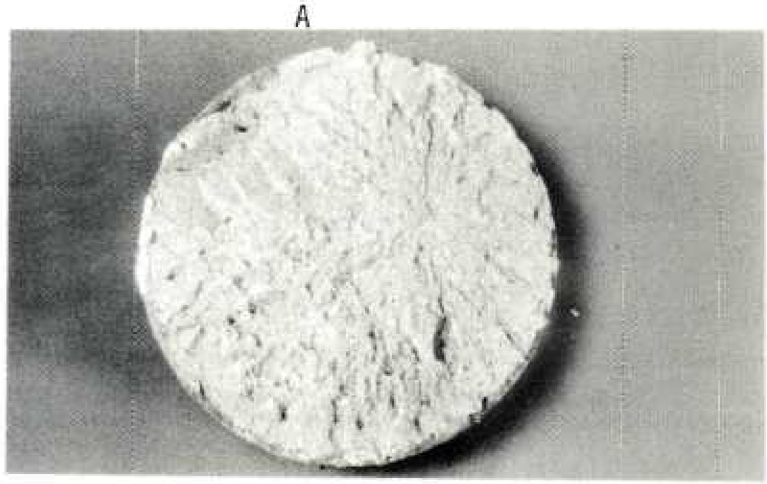
C

Figure H12. Bethlehem Steel Longitudinal Section of Billet 20C.
(a) Tensile Bar. 0.8x (b) Fractured Surface. 5x
(c) Heat Treatment. 500x 2% Nital.

BETHLEHEM STEEL



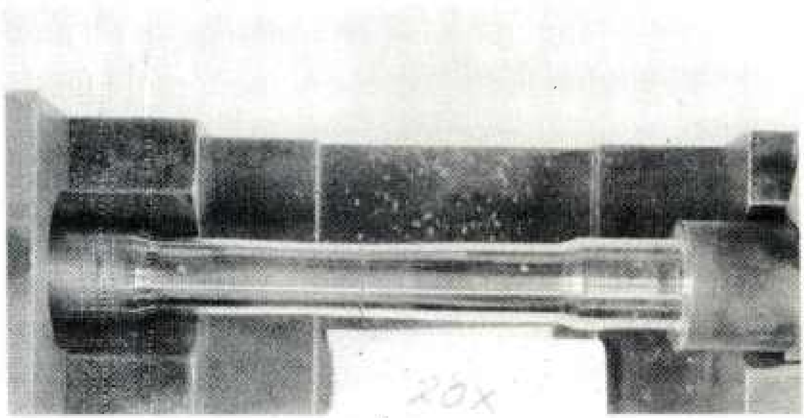
A



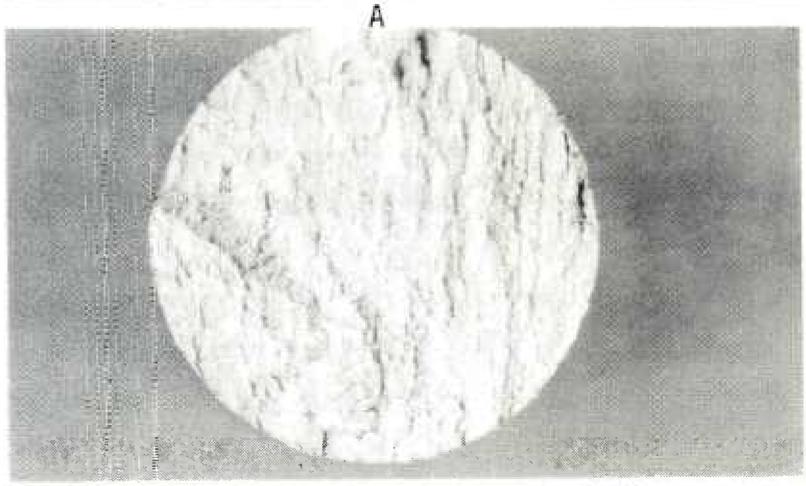
B

C

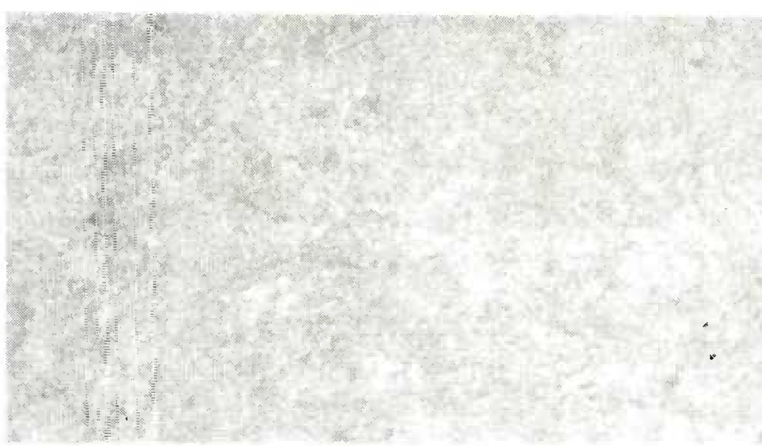
Figure H13. Bethlehem Steel Longitudinal Section of Billet 20X.
(a) Tensile Bar. 0.8x (b) Fractured Surface. 5x
(c) Heat Treatment. 1500x 2% Nital.



A



B



C

Figure H14. Bethlehem Steel Transverse Section of Billet 20X.
(a) Tensile Bar. 0.8x (b) Fractured Surface. 5x
(c) Heat Treatment. 500x 2% Nital.

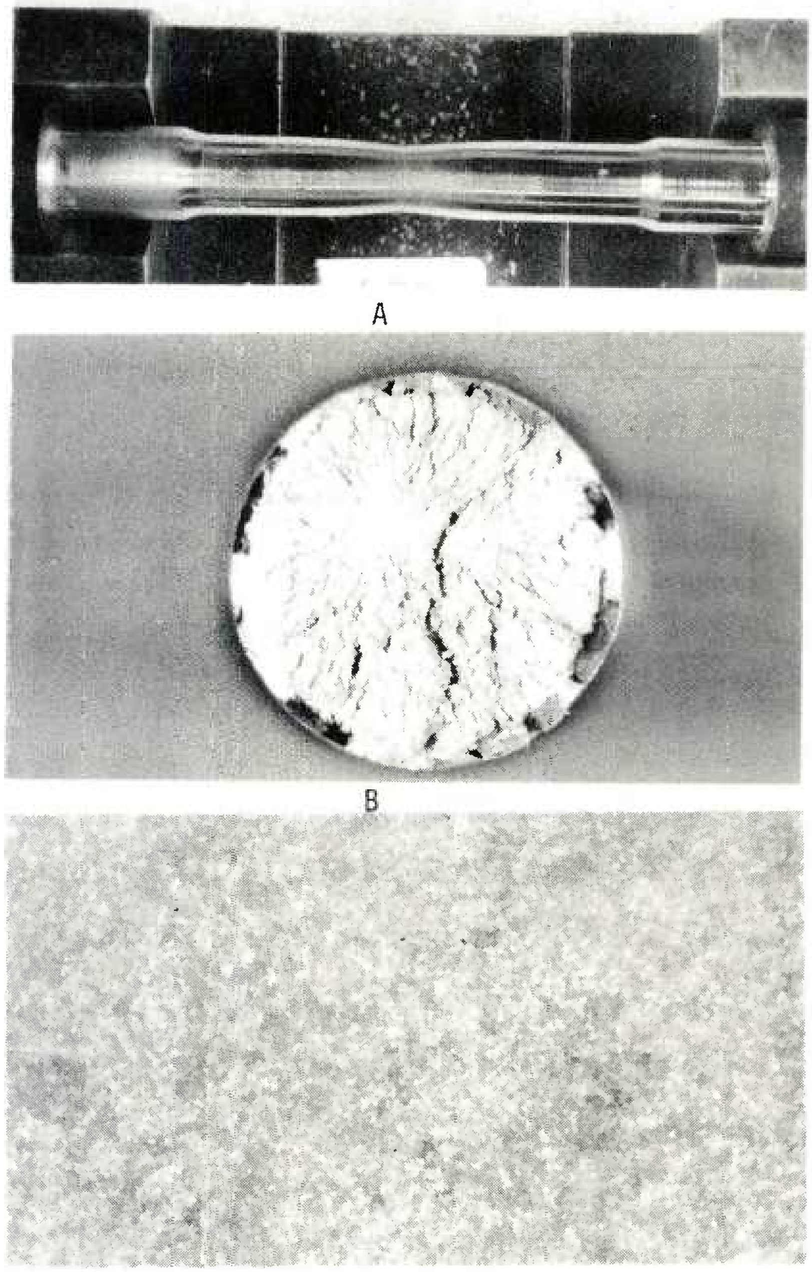
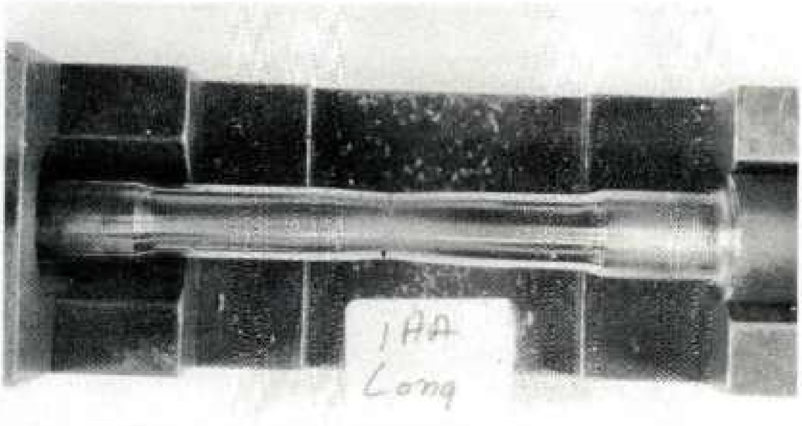
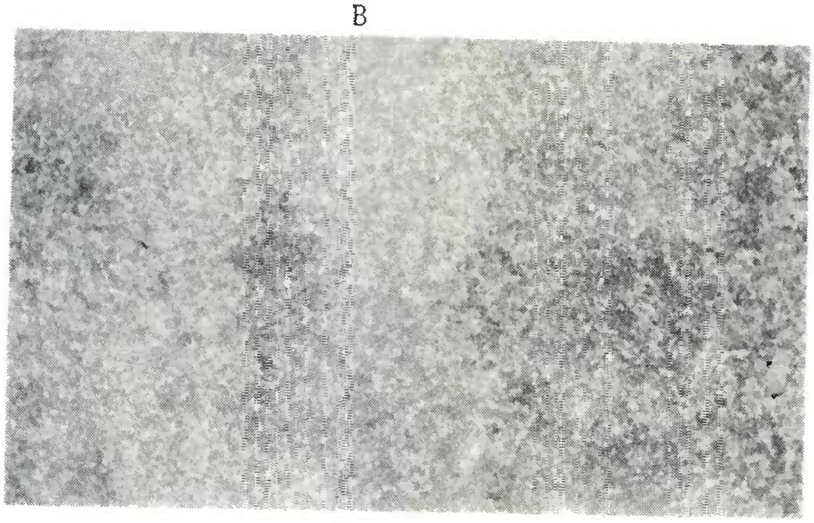


Figure H15. Republic Steel Longitudinal Section of Billet 1BD.
(a) Tensile Bar. 0.8x (b) Fractured Surface. 5x
(c) Heat Treatment. _500x 2% Nital.



A

B



C

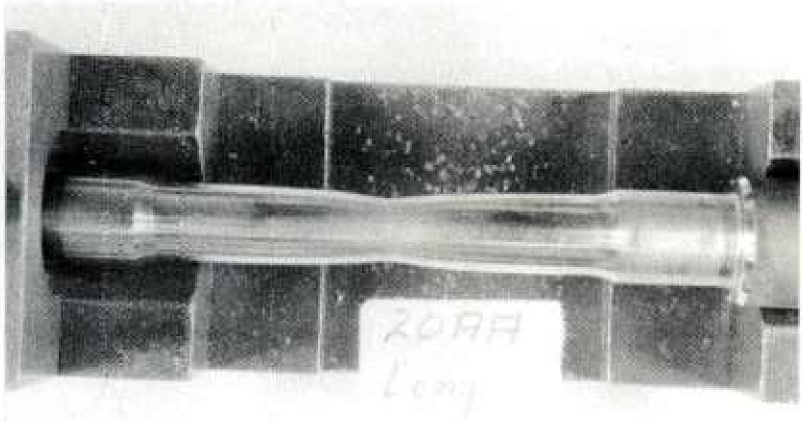
Figure H16. Republic Steel Longitudinal Section of Billet 14A.
(a) Tensile Bar. 0.8x (b) Fractured Surface. 5x
(c) Heat Treatment. 500x 2% Nital.

A

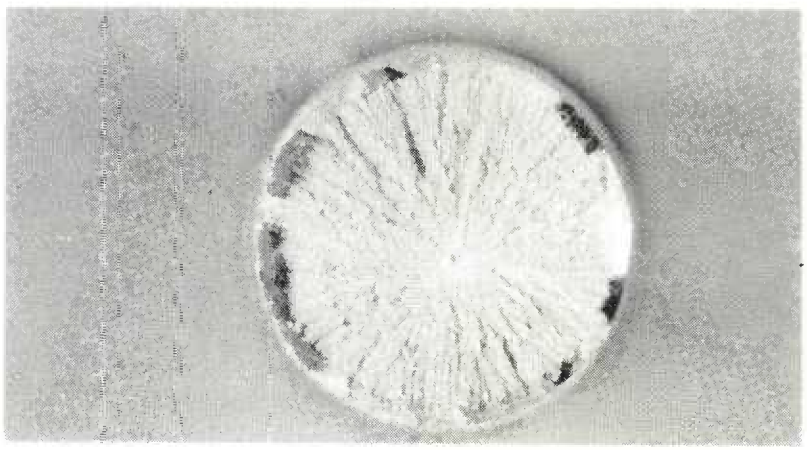
B

C

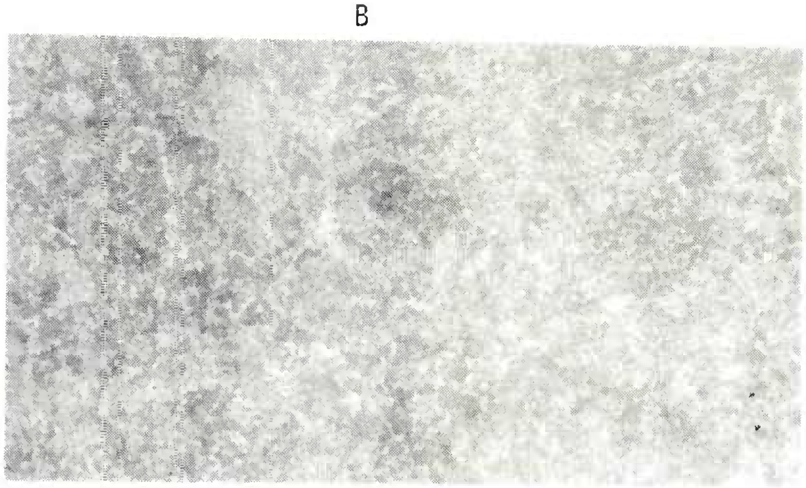
Figure H17. Republic Steel Transverse Section of Billet 1AA.
(a) Tensile Bar. 0.8x (b) Fractured Surface. 5x
(c) Heat Treatment. 500x 2% Nital.



A

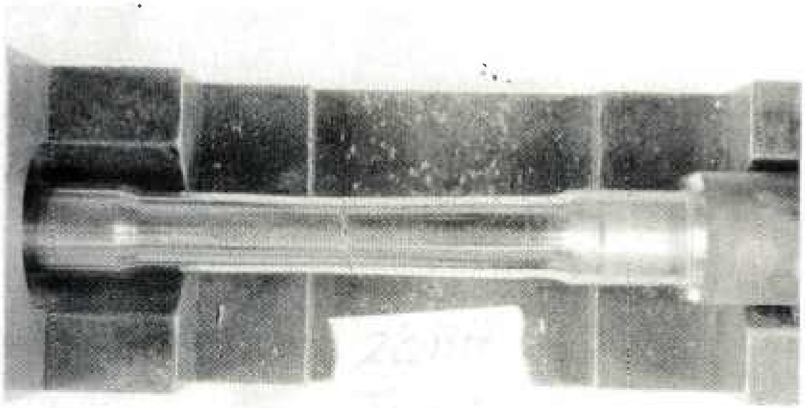


B



C

Figure H18. Republic Steel Longitudinal Section of Billet 20AA.
(a) Tensile Bar. 0.8x (b) Fractured Surface. 5x
(c) Heat Treatment. 500x 2% Nital.

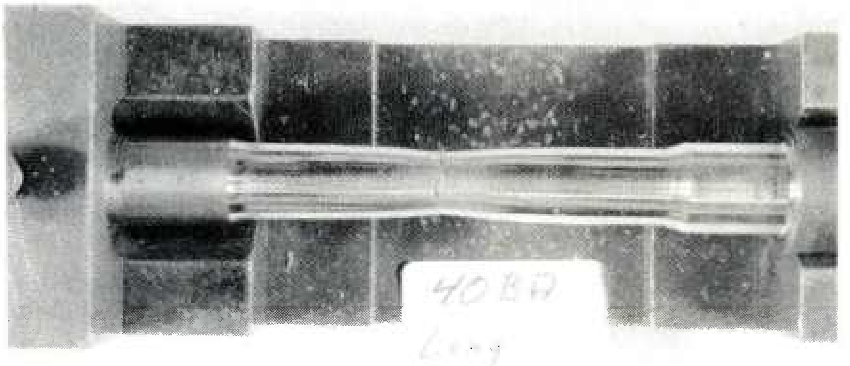


A

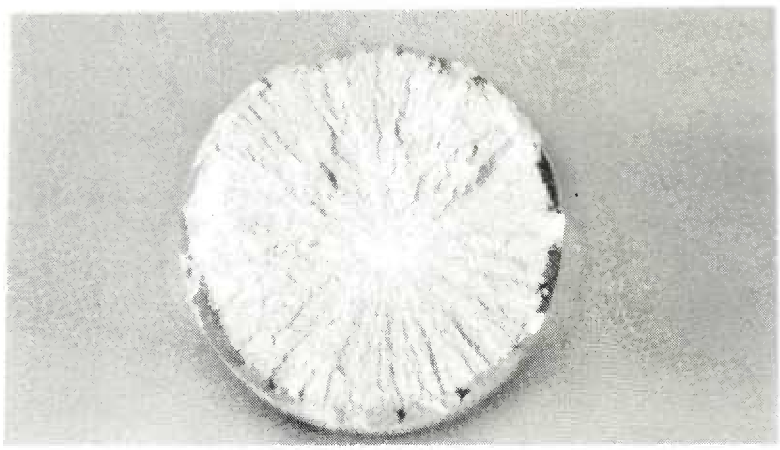
B

C

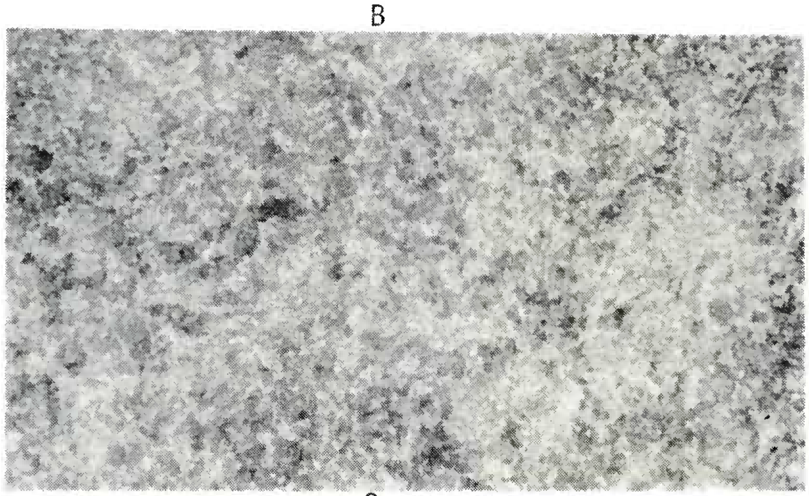
Figure H19. Republic Steel Transverse Section of Billet 20BA.
(a) Tensile Bar. 0.8x (b) Fractured Surface. 5x
(c) Heat Treatment. 500x 2% Nital.



A



B

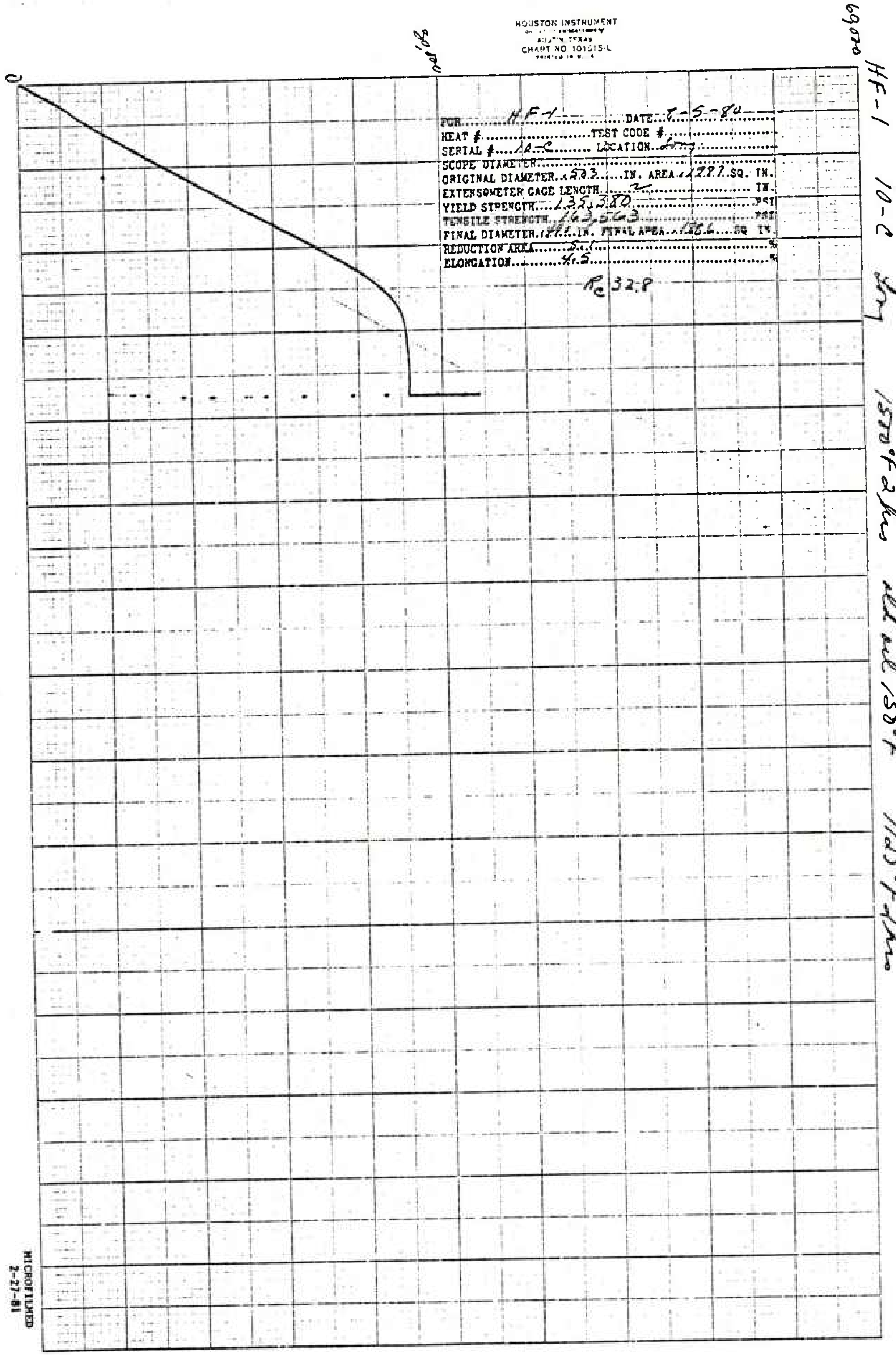


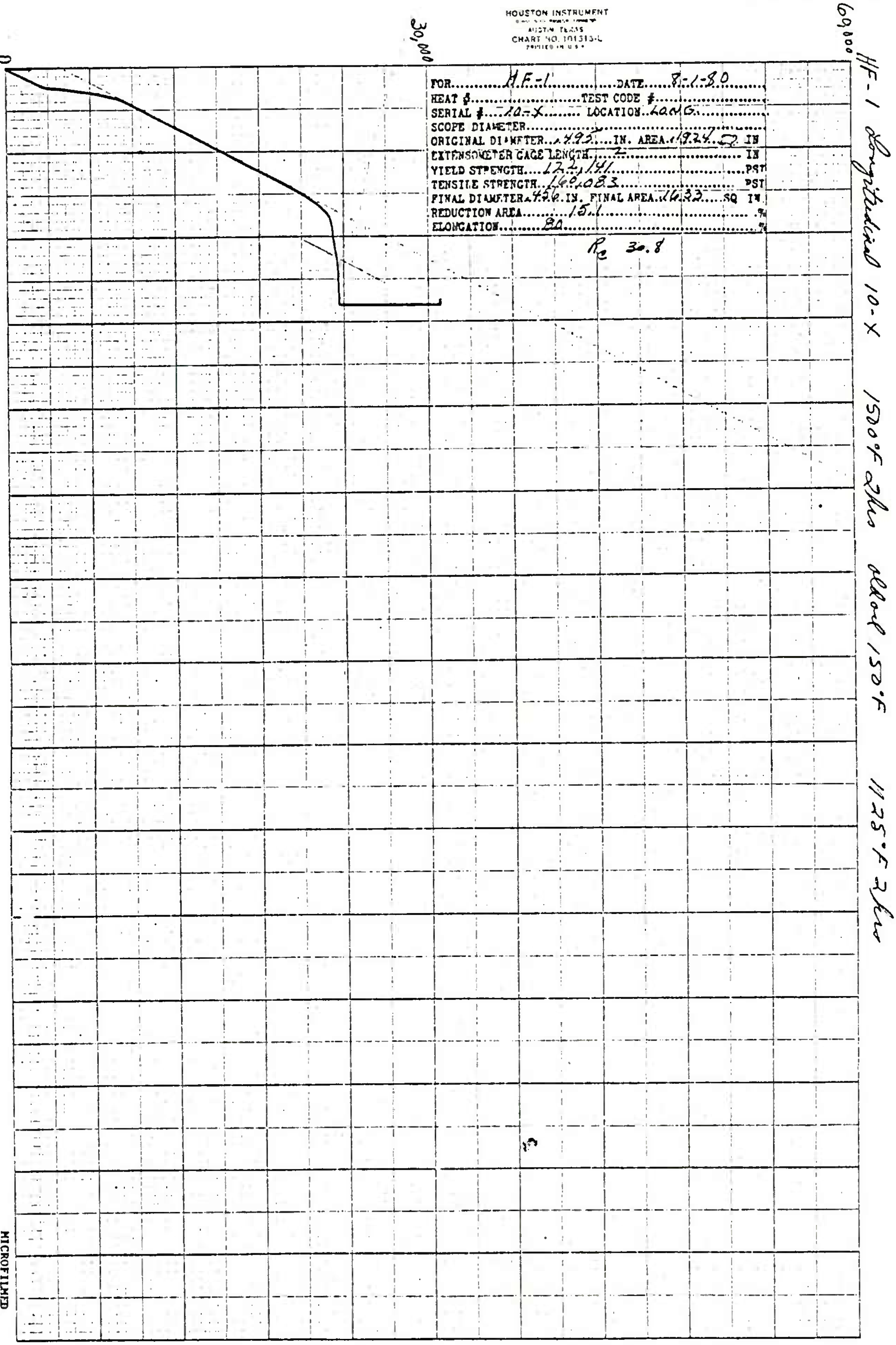
C

Figure H20. Republic Steel Longitudinal Section of Billet 40BA.
(a) Tensile Bar. 0.8x (b) Fractured Surface. 5x
(c) Heat Treatment. 500x 2% Nital.

Appendix I

Stress Strain Curves

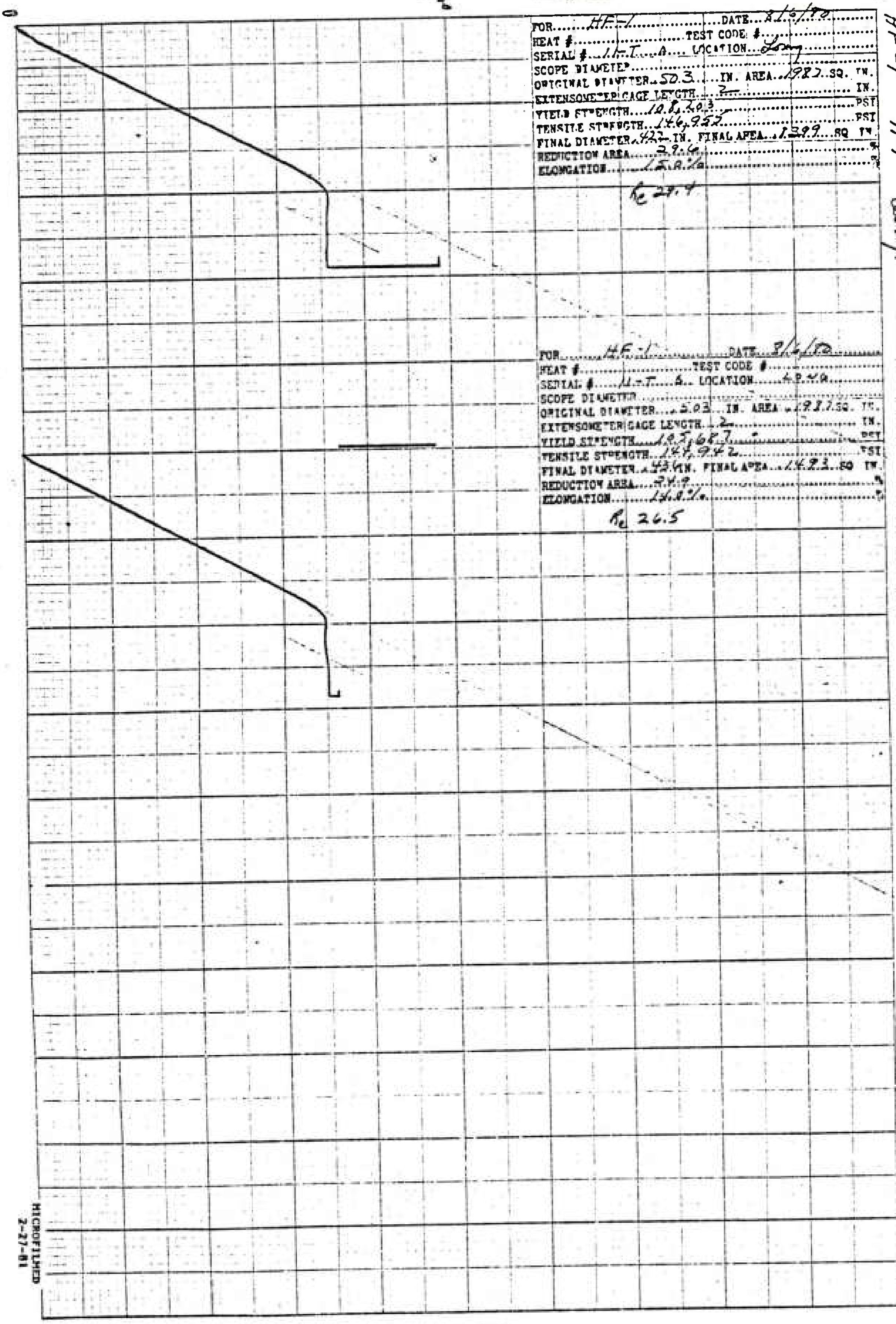

HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
0
80,000
69000 HF-1 10-C Long 1570°F 2hrs Std oil 150°F 1125°F 2hrs
FOR HF-1 DATE 8-5-80
HEAT # TEST CODE #
SERIAL # 10-C LOCATION Long
SCOPE DIAMETER
ORIGINAL DIAMETER .503 IN. AREA .1987 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 135,380 PSI
TENSILE STRENGTH 163,563 PSI
FINAL DIAMETER .491 IN. FINAL AREA .1886 SQ IN.
REDUCTION AREA 5.1 %
ELONGATION 4.5 %
Rc 32.8
MICROFILMED 2-27-81

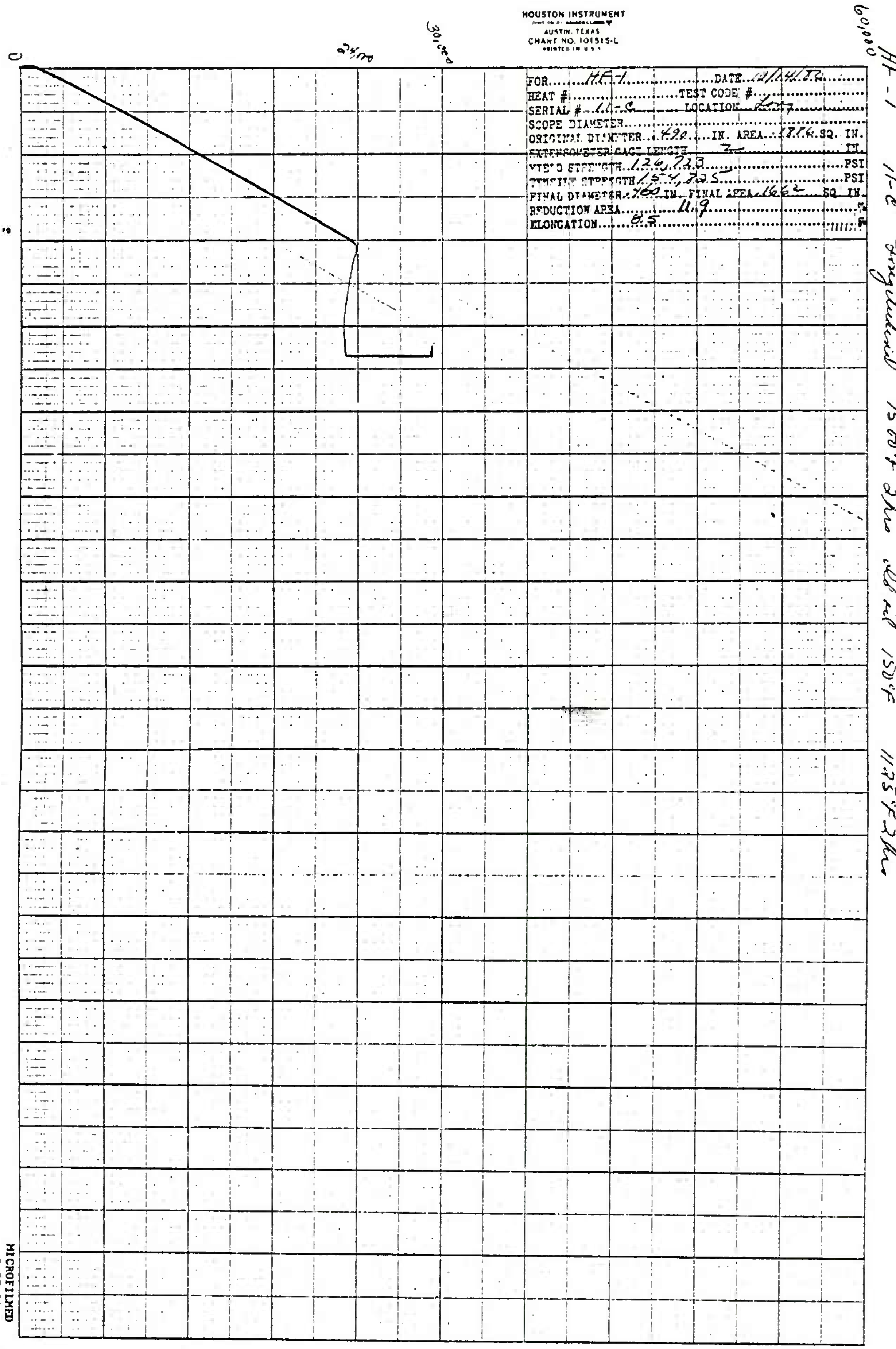


MICROFILMED 2-27-81

2

HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L

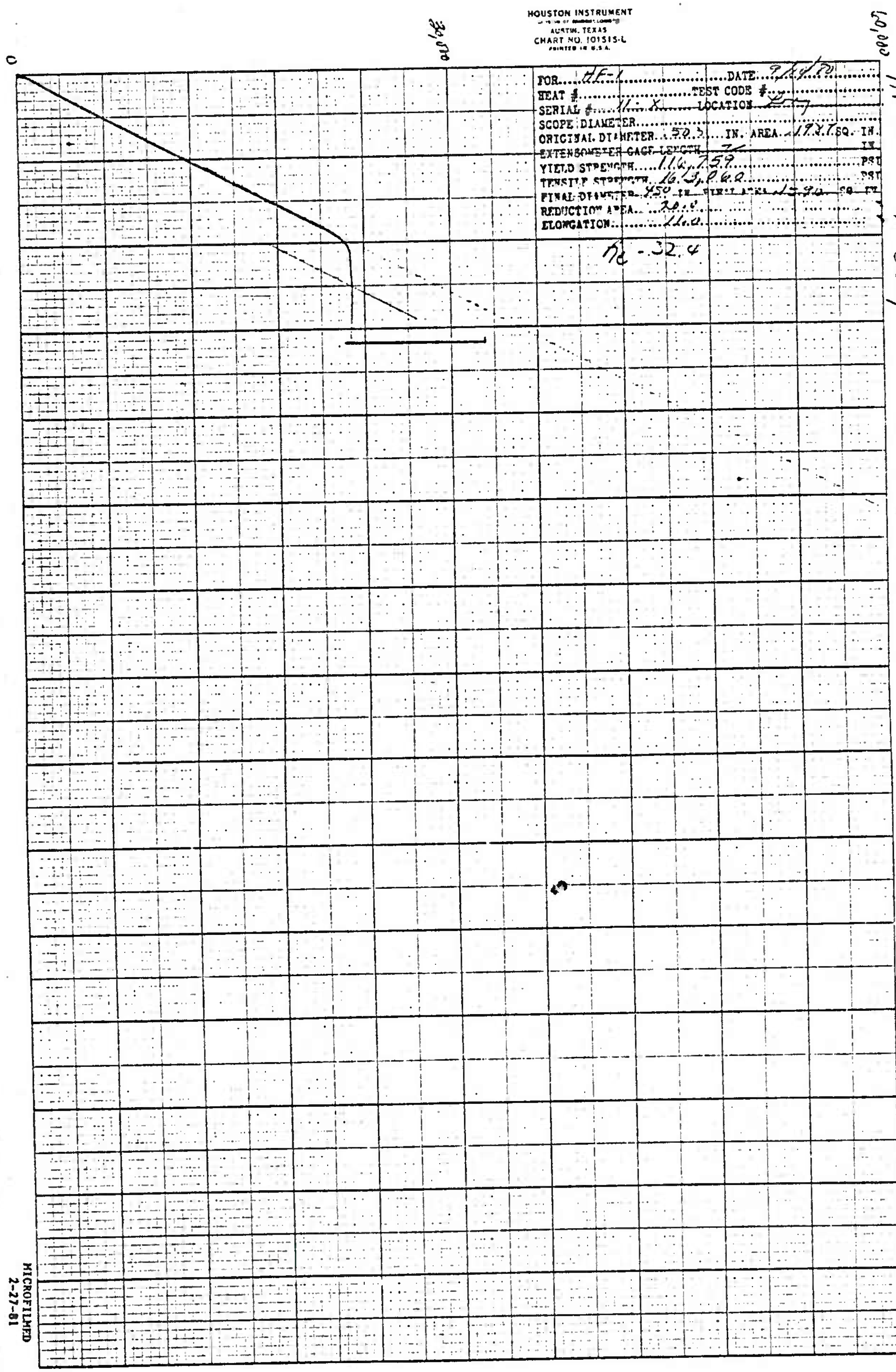




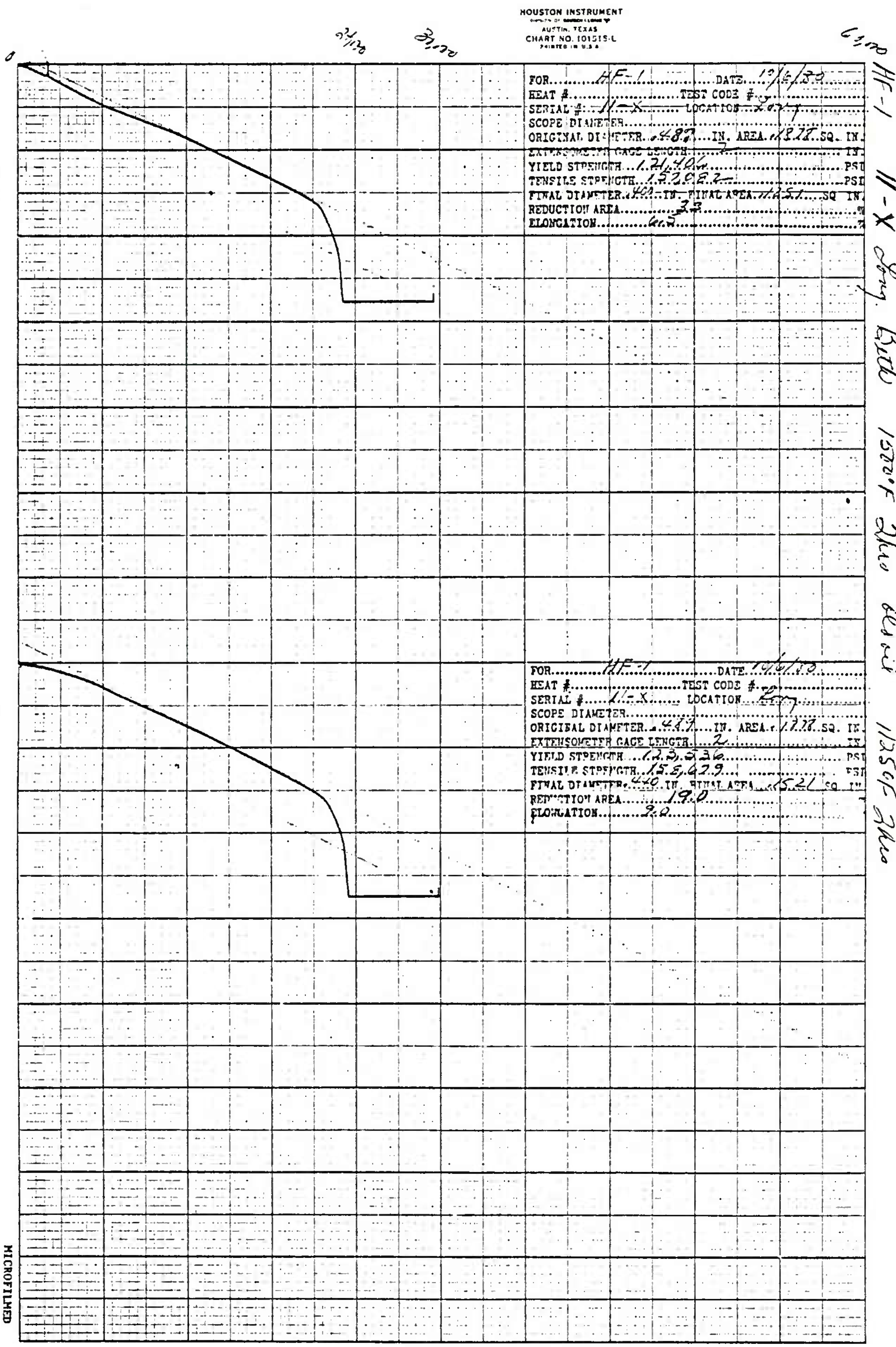
FOR HF-1 DATE 12/14/72
HEAT # TEST CODE #
SERIAL # 11-C LOCATION Long
SCOPE DIAMETER
ORIGINAL DIAMETER .490 IN. AREA .1886 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 126,723 PSI
TENSILE STRENGTH 154,725 PSI
FINAL DIAMETER .460 IN. FINAL AREA .1662 SQ. IN.
REDUCTION AREA 11.9 %
ELONGATION 8.5 %

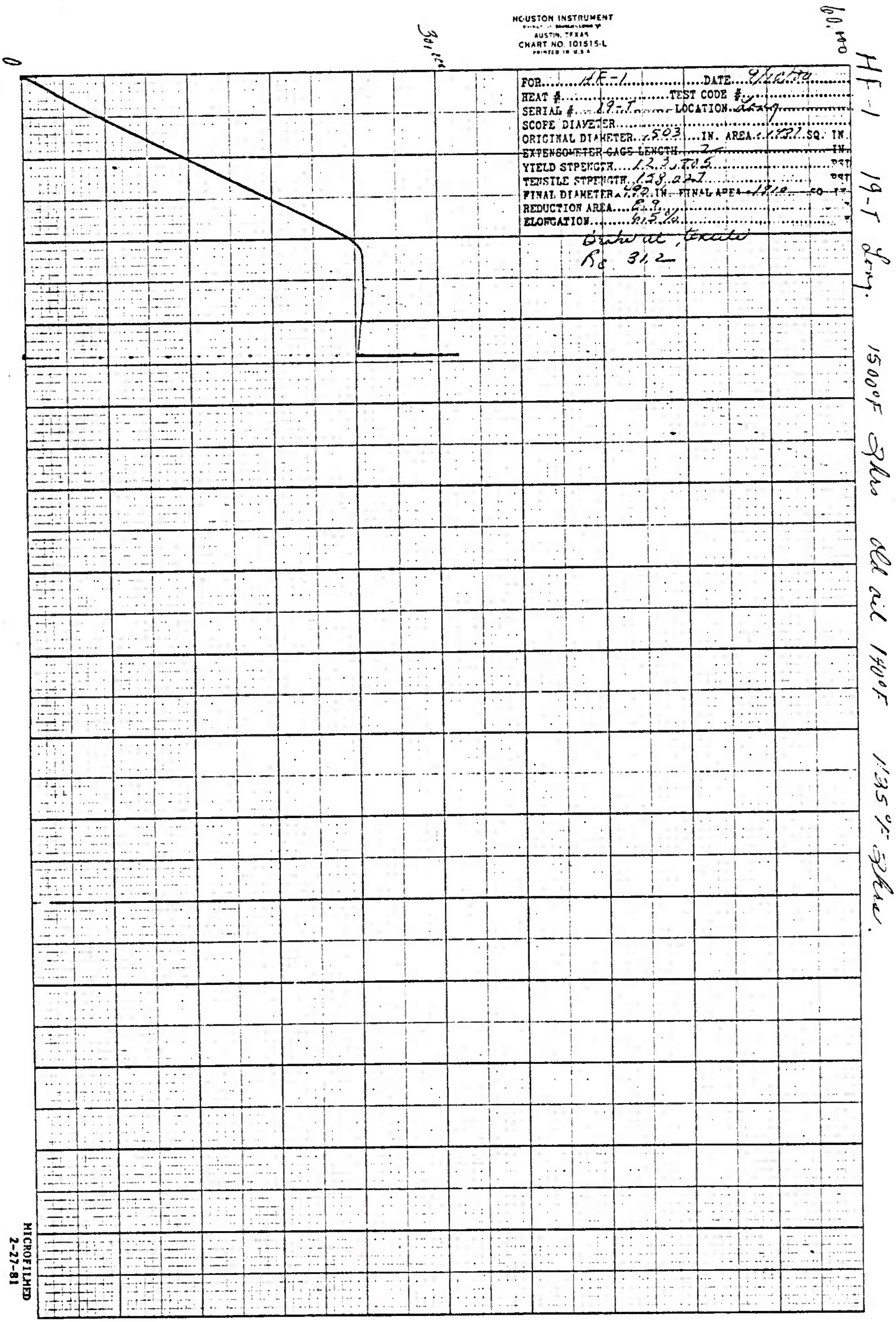
MICROFILMED
2-27-81

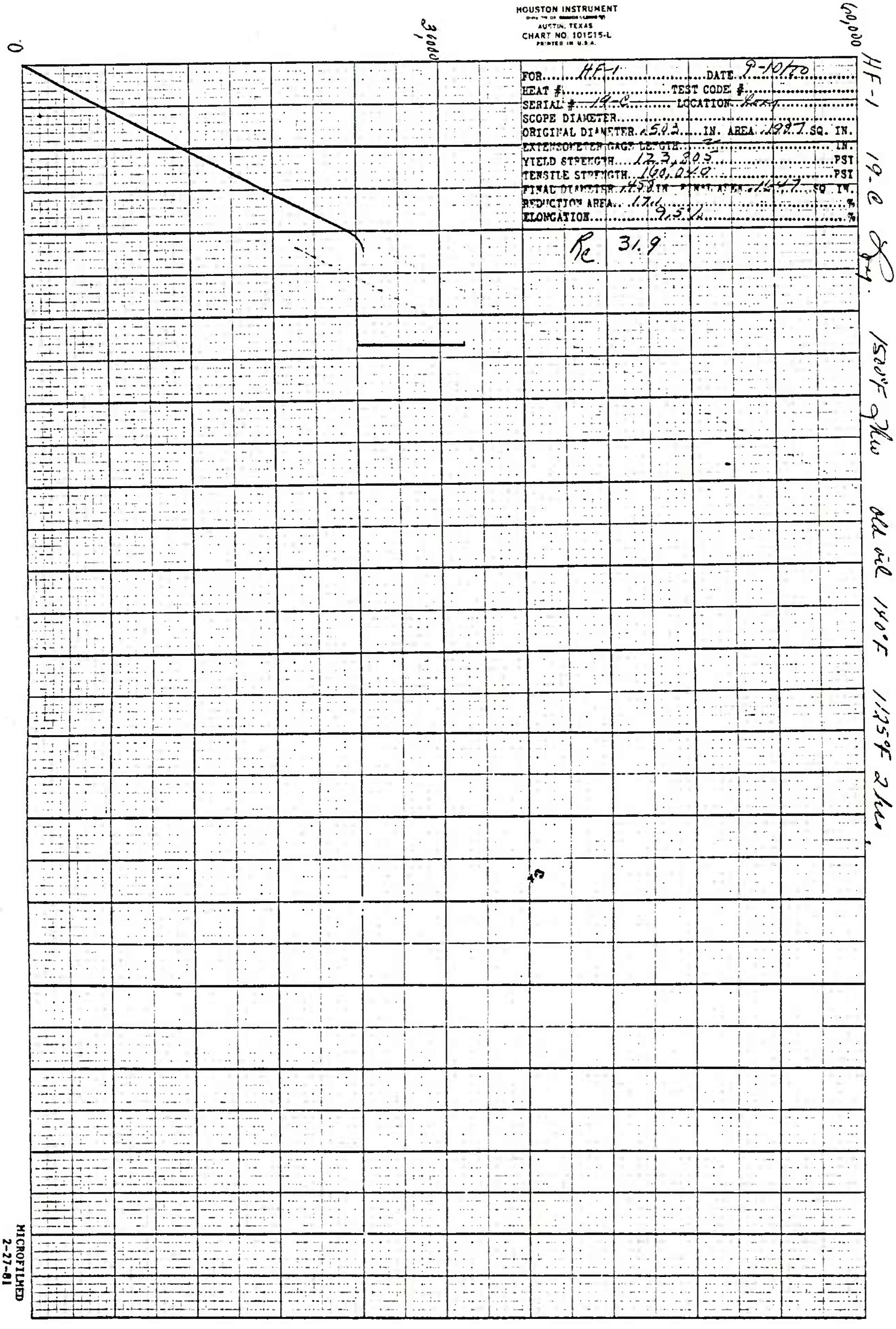
4



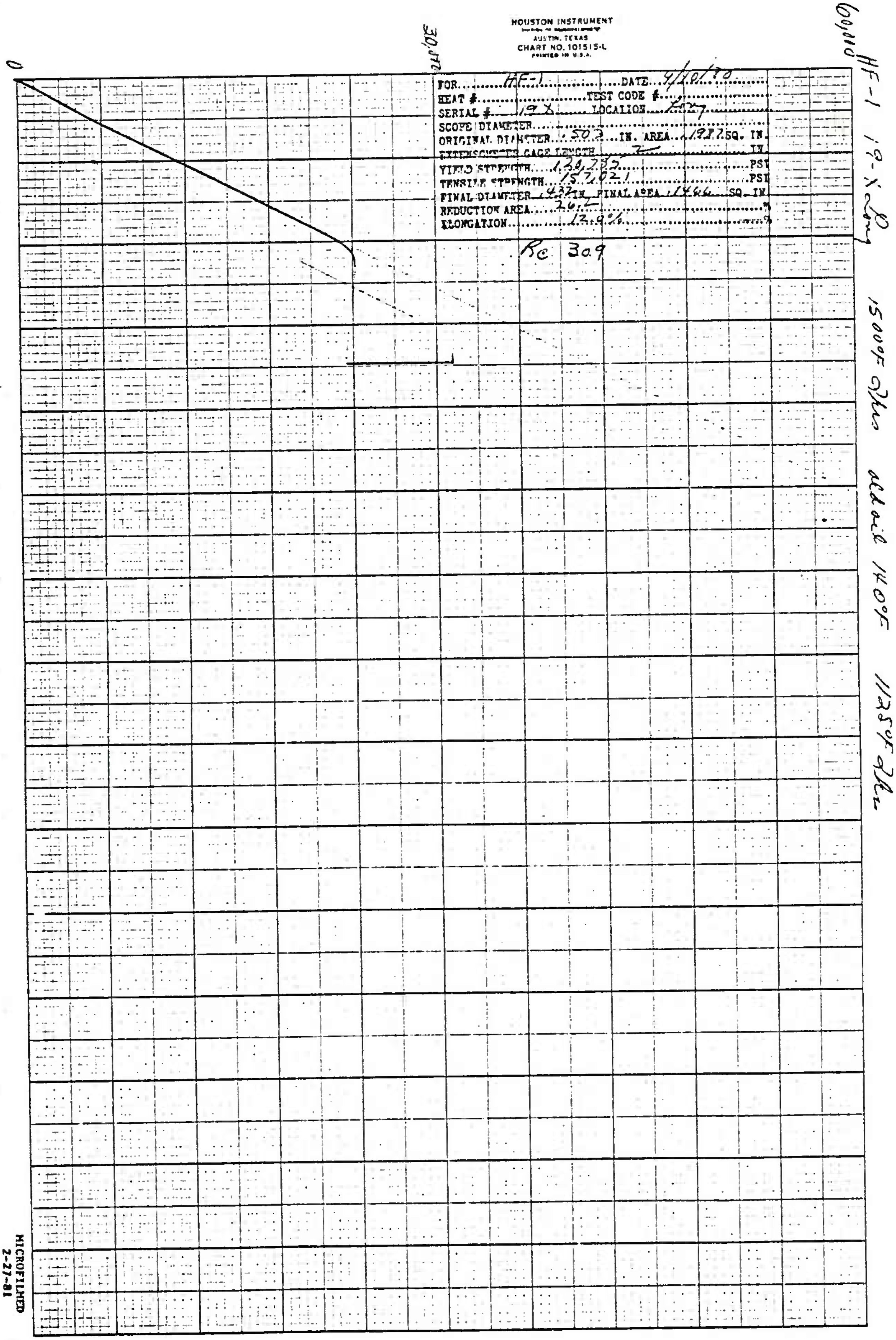
HF-1 11-X Long 1500°F 3hrs Air/140° 1125°F 2hrs


HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
PRINTED IN U.S.A.
FOR HF-1 DATE 12/6/80
HEAT # TEST CODE # 7
SERIAL # 11-X LOCATION Long
SCOPE DIAMETER
ORIGINAL DIAMETER .487 IN. AREA .1878 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 121,404 PSI
TENSILE STRENGTH 152,082 PSI
FINAL DIAMETER .400 IN. FINAL AREA .1251 SQ. IN.
REDUCTION AREA 33 %
ELONGATION 6.5 %
FOR HF-1 DATE 12/6/80
HEAT # TEST CODE #
SERIAL # 11-X LOCATION Long
SCOPE DIAMETER
ORIGINAL DIAMETER .487 IN. AREA .1878 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 123,536 PSI
TENSILE STRENGTH 155,629 PSI
FINAL DIAMETER .440 IN. FINAL AREA .1521 SQ. IN.
REDUCTION AREA 19.0
ELONGATION 9.0


HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
PRINTED IN U.S.A.
0
30,000
60,000
FOR HF-1 DATE 9/26/70
HEAT #
TEST CODE #
SERIAL # 19-T
LOCATION Long
SCOPE DIAMETER
ORIGINAL DIAMETER .503 IN. AREA .1931 SQ. IN.
~~EXTENSOMETER GAGE LENGTH~~ 2 IN.
YIELD STRENGTH 123,705 PSI
TENSILE STRENGTH 128,227 PSI
FINAL DIAMETER .492 IN. FINAL AREA .1910 SQ. IN.
REDUCTION AREA 2.9
ELONGATION 21.5 %
Broke at , treated
Rc 31.2
HF-1 19-T Long. 1500°F 3 hr. Oil 1400°F 1135°F 3 hr.
7

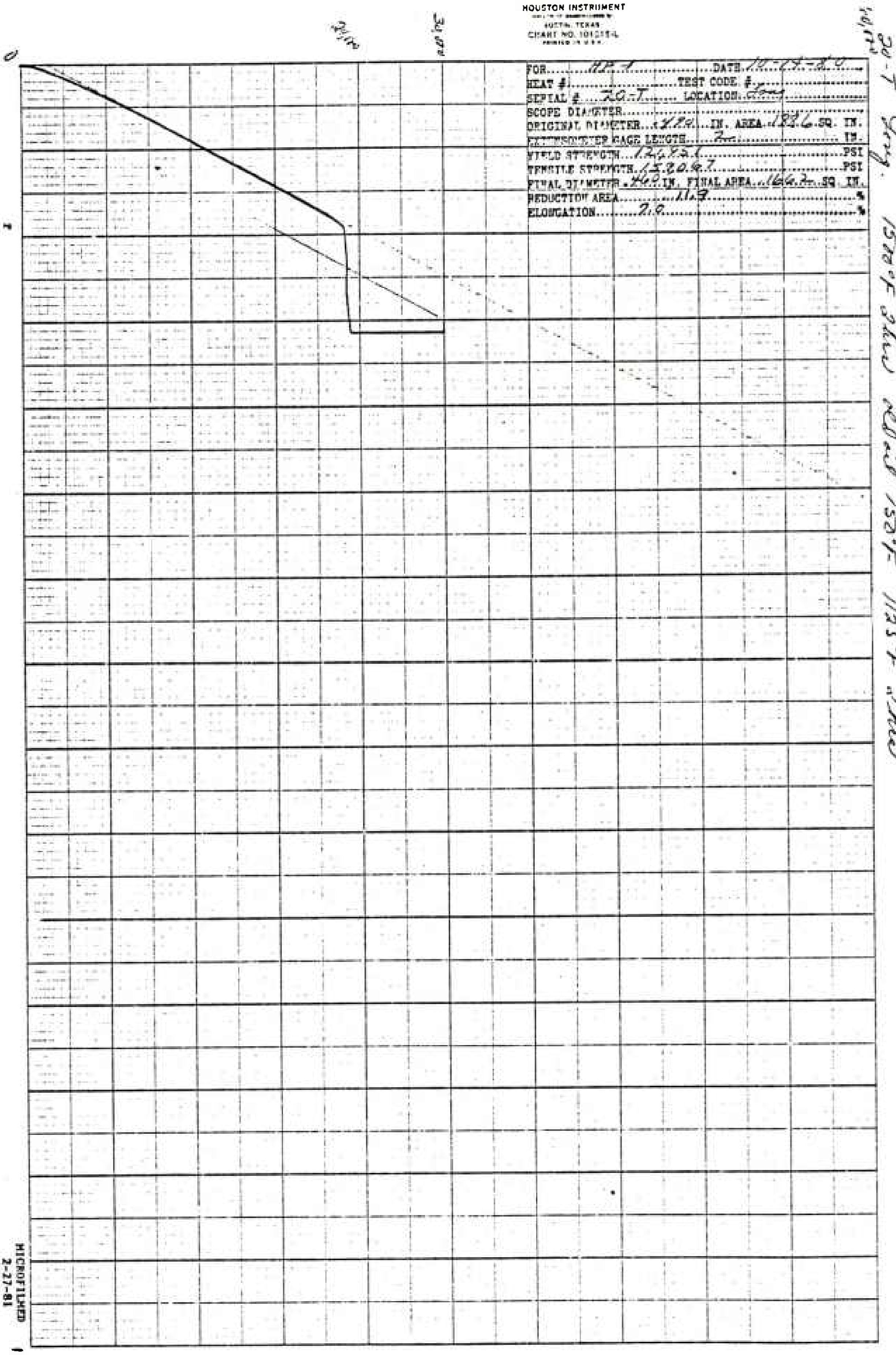


MICROFILMED 2-27-81

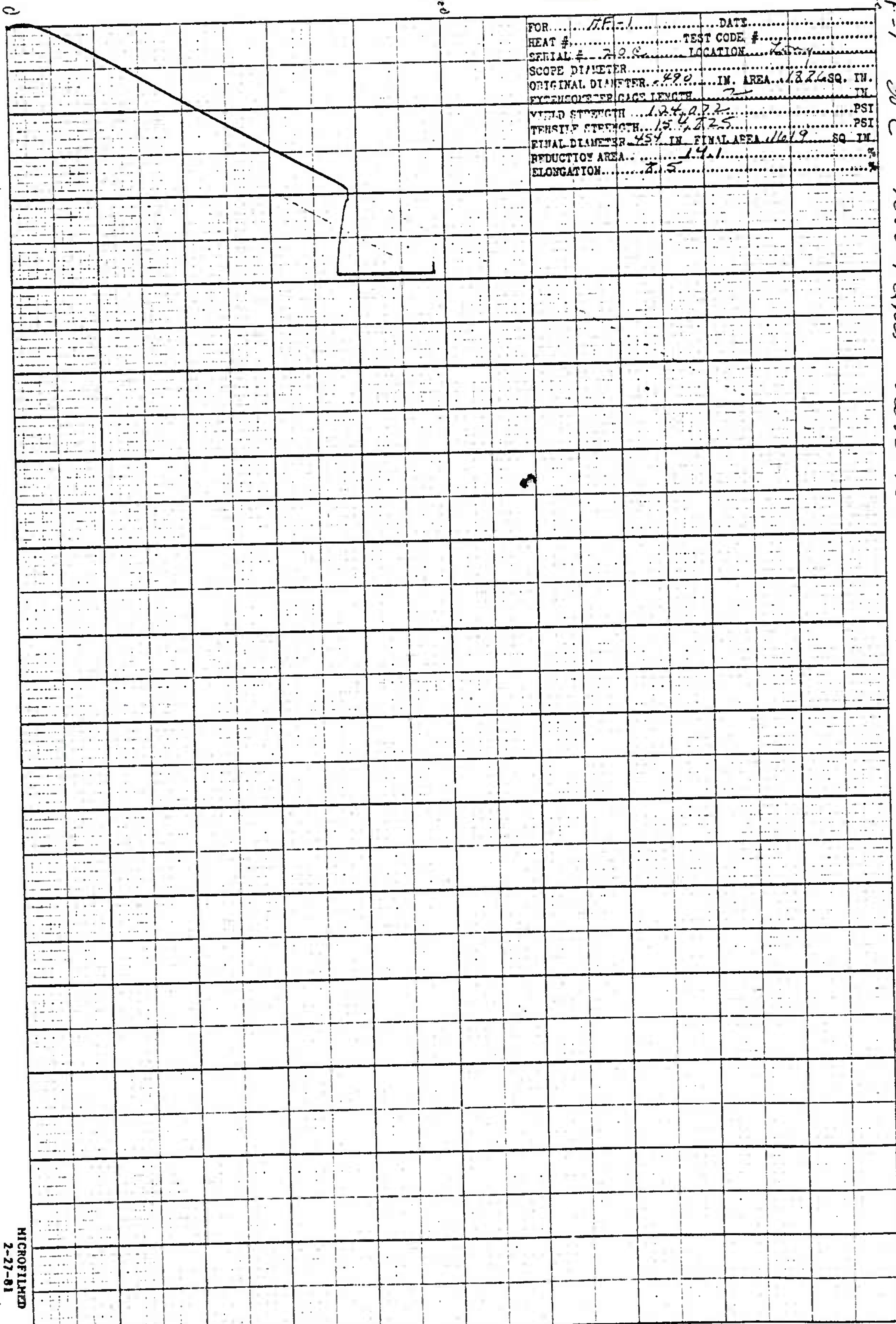


MICROFILMED
2-27-81

9

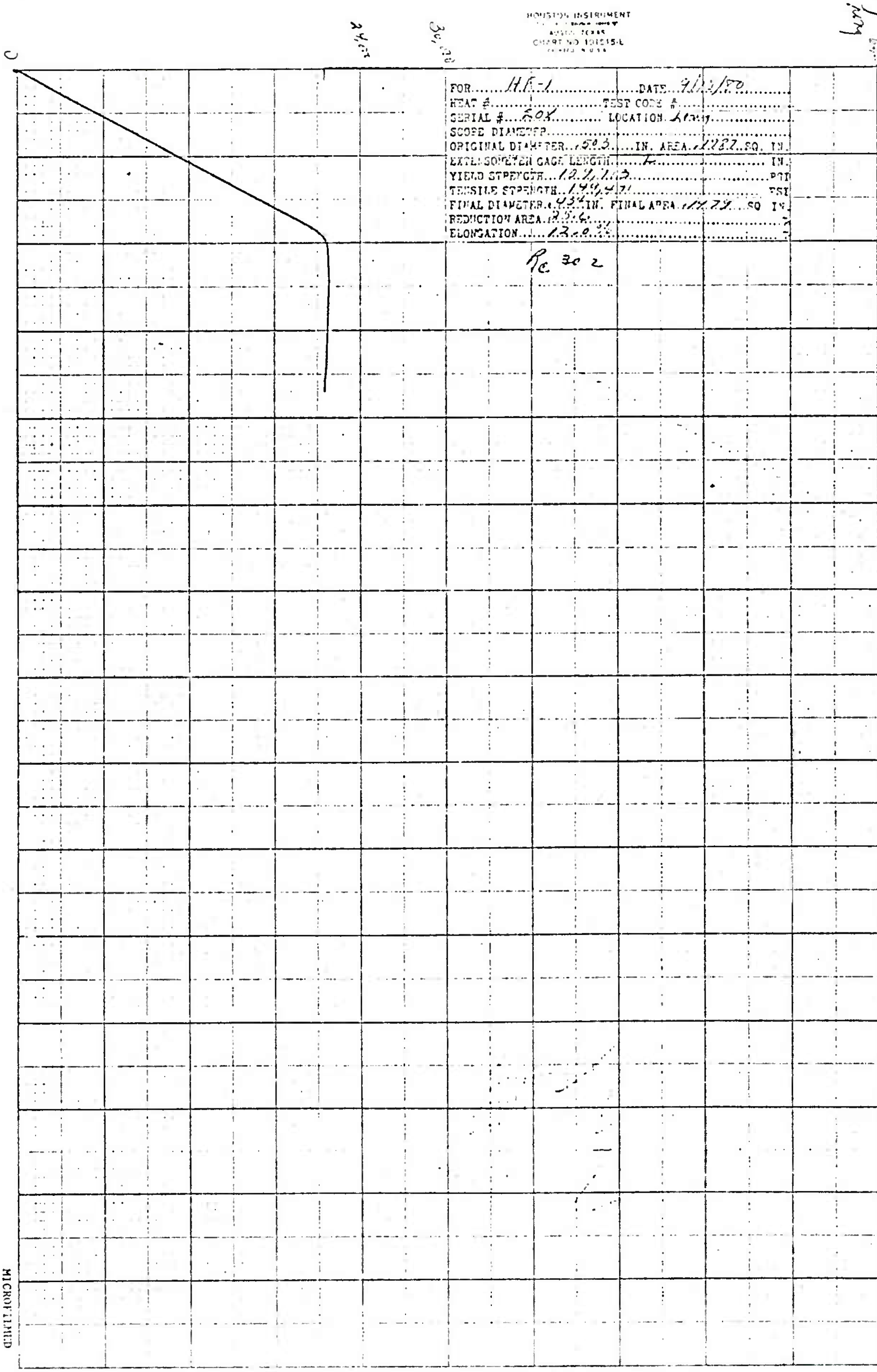

HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101215-L
PRINTED IN U.S.A.
0
10
29,100
30,000
FOR HP-1 DATE 10-23-80
HEAT #
TEST CODE #
SERIAL # 20-T LOCATION Long
SCOPE DIAMETER
ORIGINAL DIAMETER .484 IN. AREA .1846 SQ. IN.
EXTENSOMETER GAGE LENGTH 2" IN.
YIELD STRENGTH 124821 PSI
TENSILE STRENGTH 152067 PSI
FINAL DIAMETER .460 IN. FINAL AREA .1662 SQ. IN.
REDUCTION AREA 11.9 %
ELONGATION 2.0 %
20-T Long. 1500°F 3hr Air cool 1520°F 1125°F 2hr

HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
PRINTED IN U.S.A.



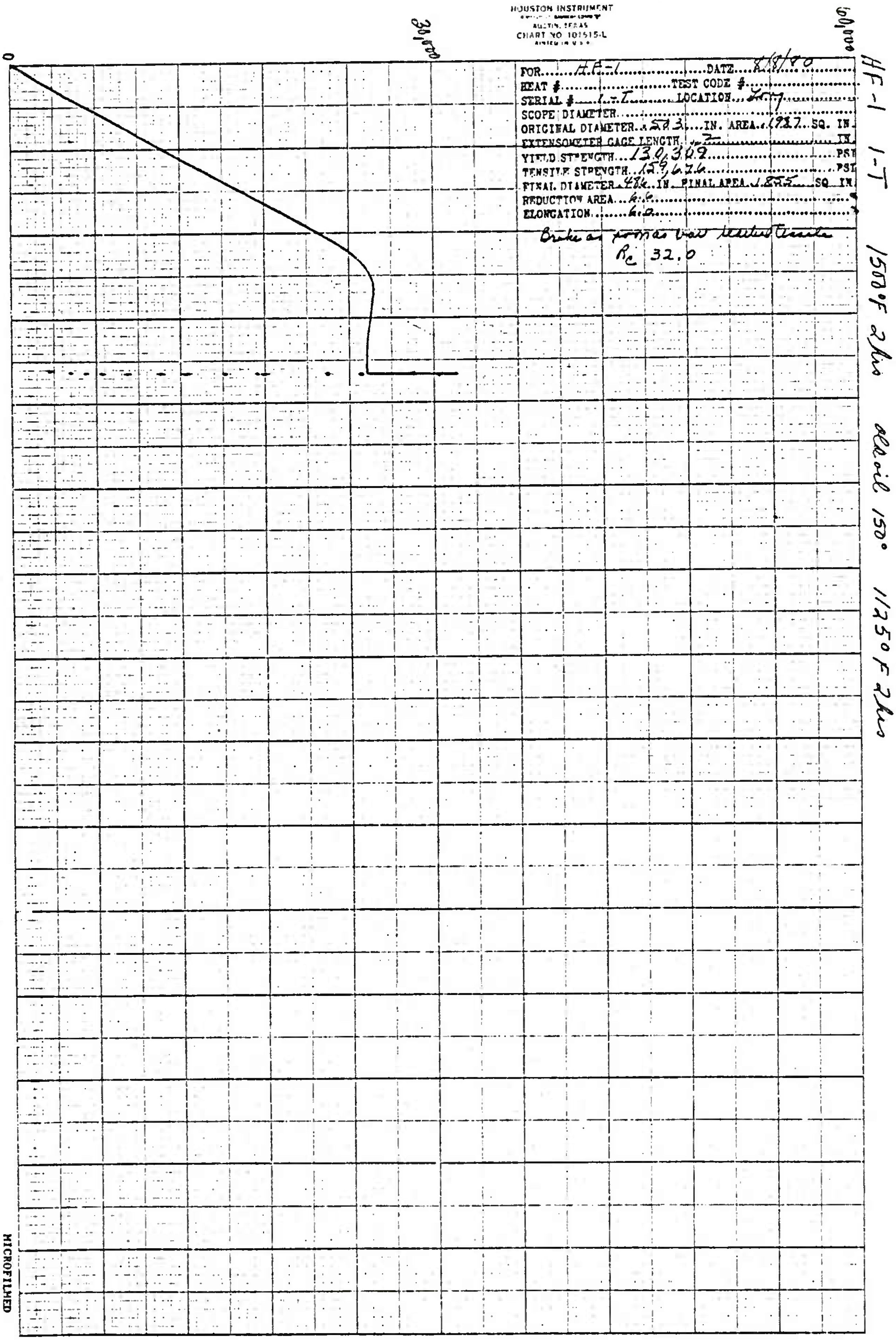
HF-1 20C 1500°F 2hrs Oil 150°F 1125°F 2hrs

MICROFILMED
2-27-81



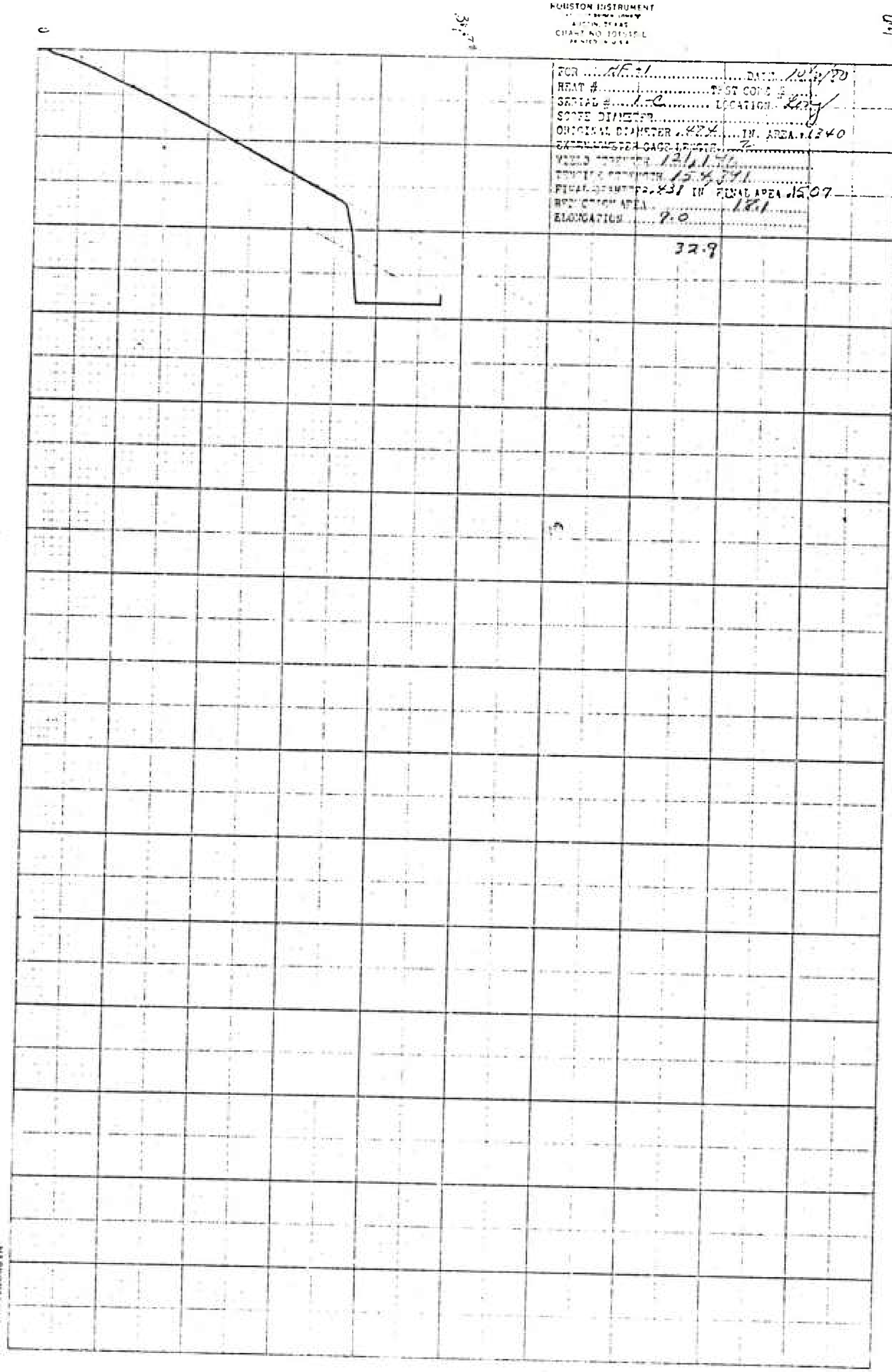
HF-1 1570°F Oil out 150°F 1125°F 3hr

MICROFILMED 2-27-81

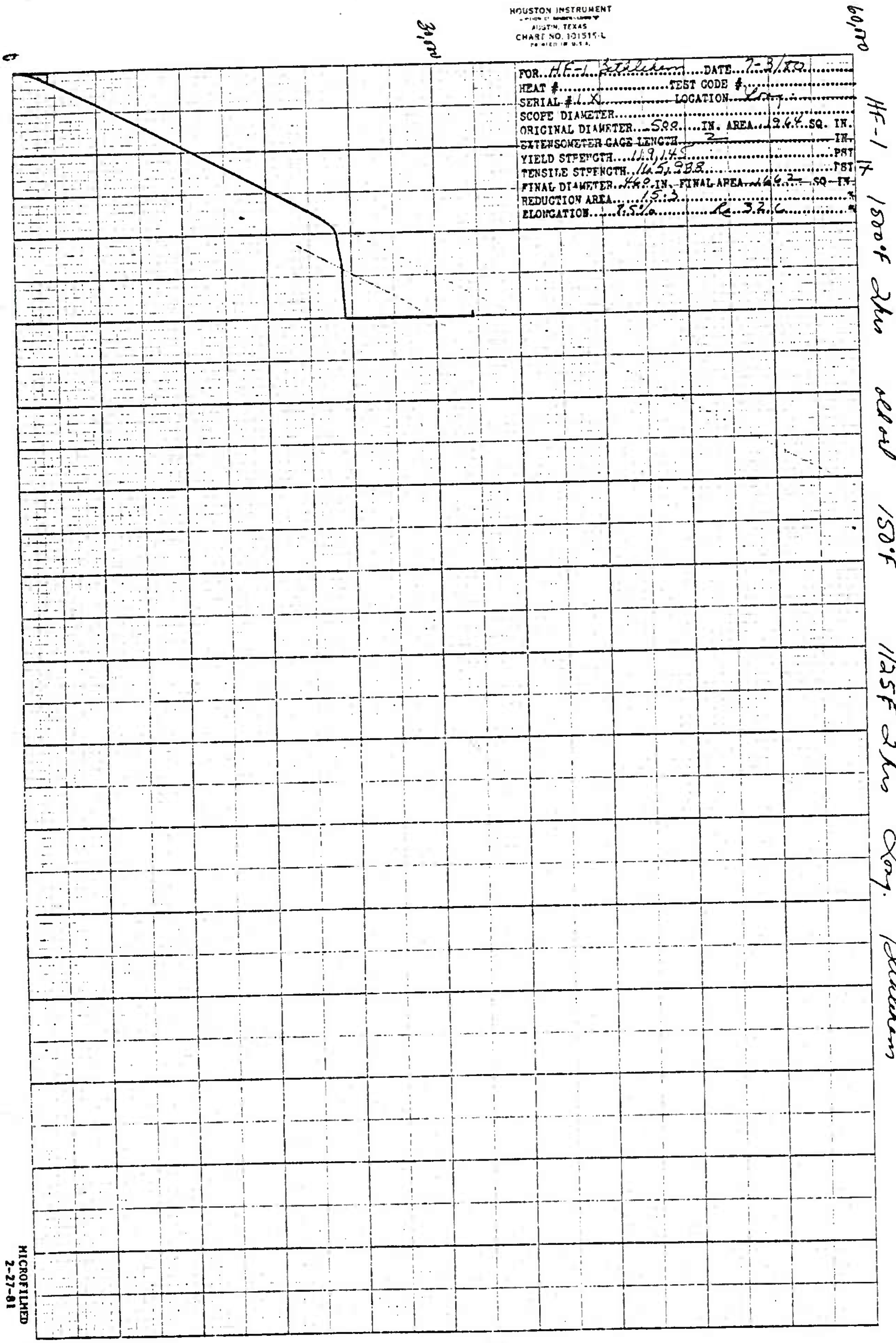


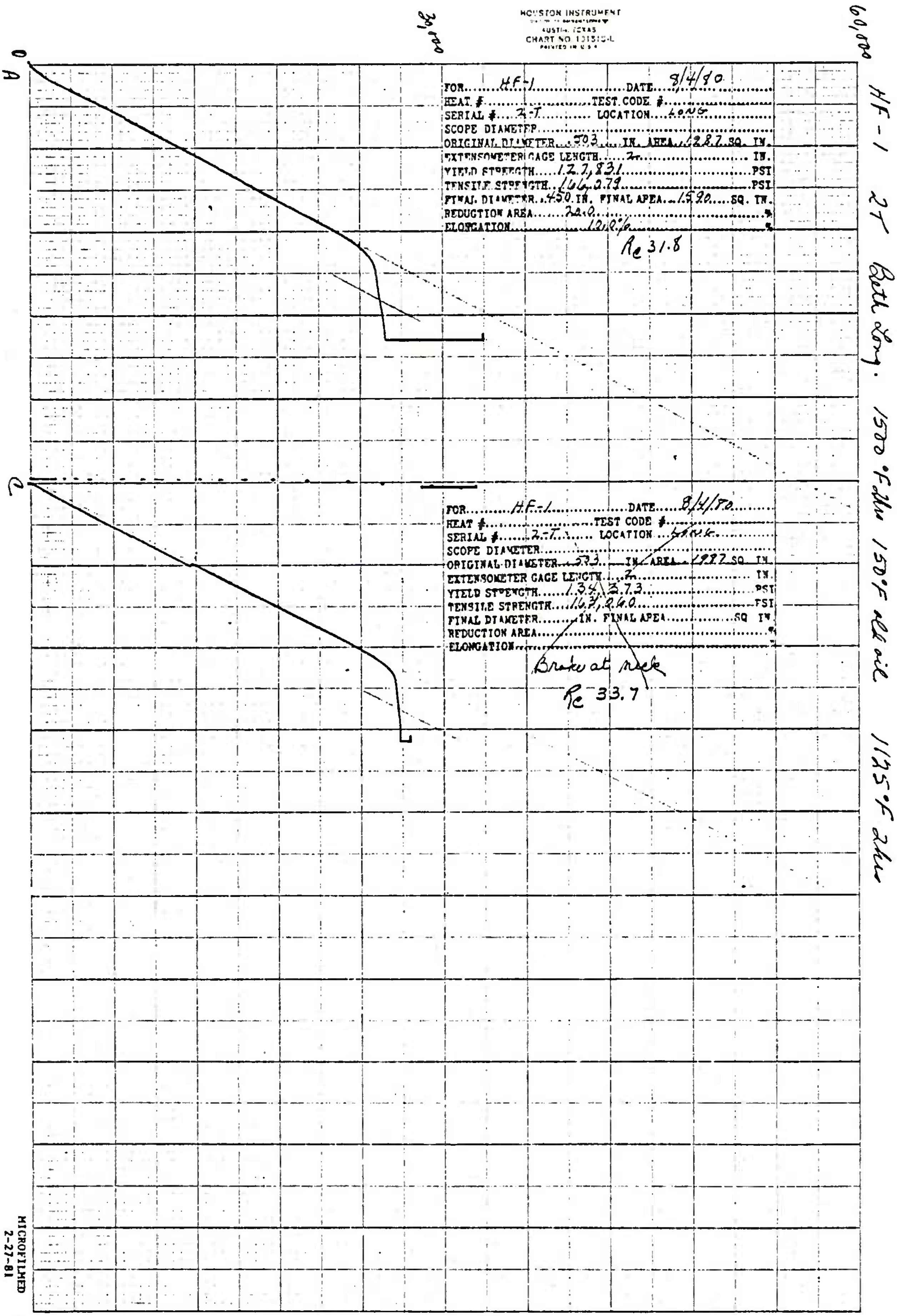
MICROFILMED
2-27-81

13



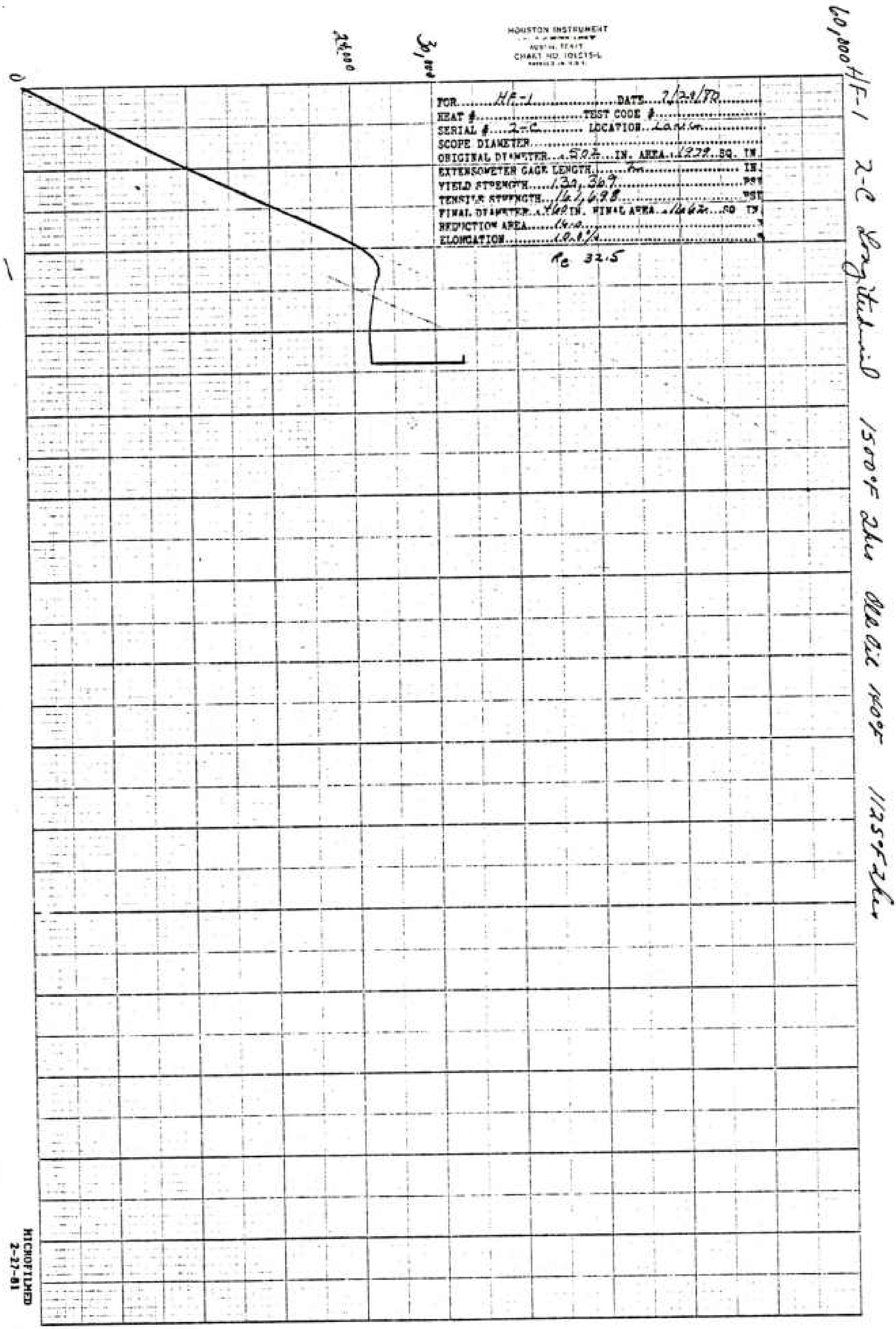
MICROFILMED
2-27-81


HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
0
30,000
60,000
FOR HF-1 Bethlehem DATE 7-3/80
HEAT # TEST CODE #
SERIAL # 1 X LOCATION Long
SCOPE DIAMETER
ORIGINAL DIAMETER .500 IN. AREA .1964 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 119,145 PSI
TENSILE STRENGTH 165,988 PSI
FINAL DIAMETER .460 IN. FINAL AREA .1662 SQ. IN.
REDUCTION AREA 15.3 %
ELONGATION 7.5% Rc 32.6 %
HF-1 1800°F 2hr oil cool 150°F 1125°F 2hr Long. Bethlehem



MICROFILMED 2-27-81

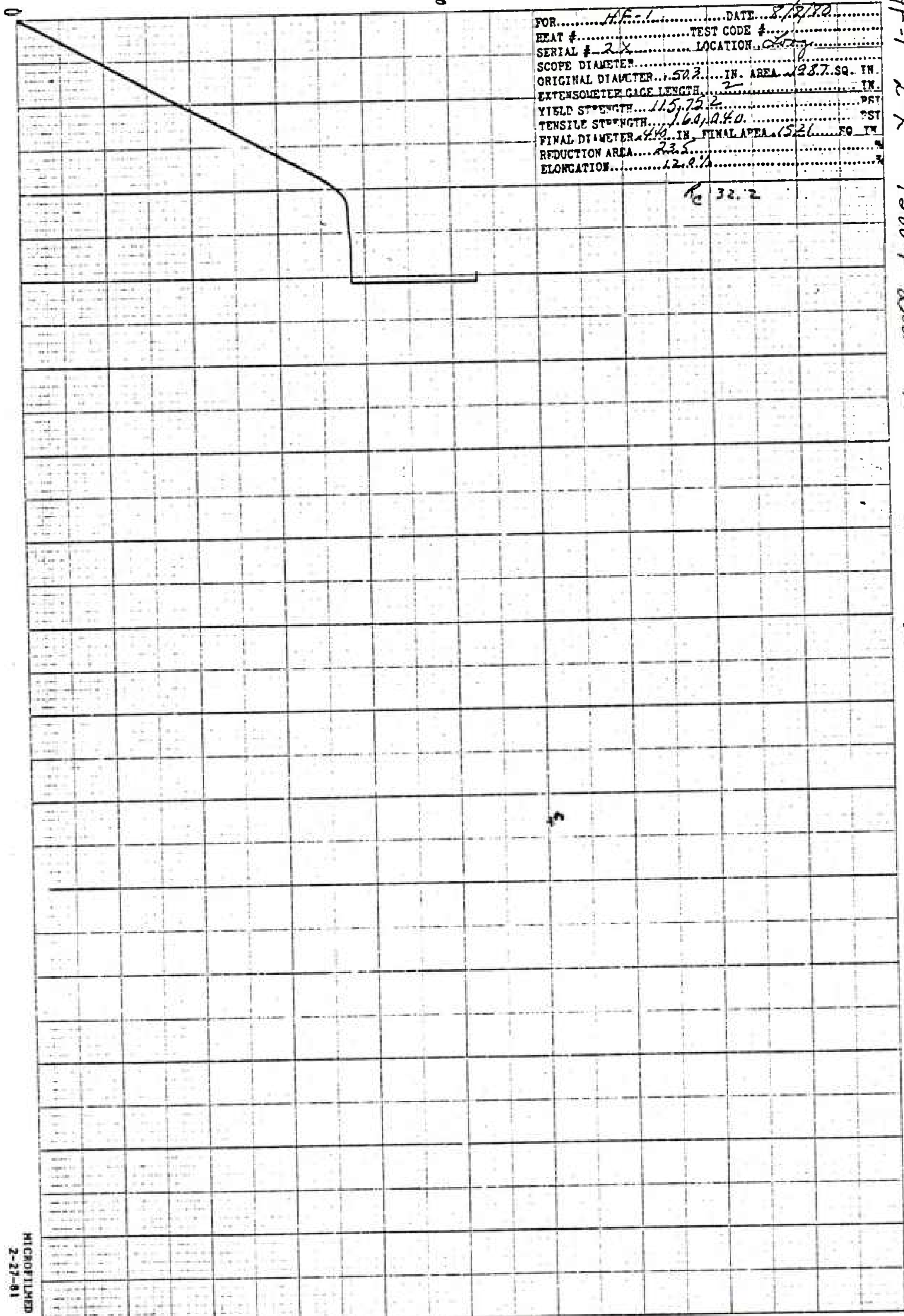
16


HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 10LC15-L
24,000
30,000
0
1
FOR HF-1 DATE 7/21/70
HEAT #
TEST CODE #
SERIAL # 2-C
LOCATION Lon
SCOPE DIAMETER
ORIGINAL DIAMETER .502 IN. AREA .1979 SQ. IN.
EXTENSOMETER GAGE LENGTH 2in IN.
YIELD STRENGTH 130,369 PSI
TENSILE STRENGTH 142,698 PSI
FINAL DIAMETER .460 IN. FINAL AREA .1662 SQ. IN.
REDUCTION AREA 16.0 %
ELONGATION 18.8 %
Rc 32.5
60,000 HF-1 2-C Longitudinal 1500°F 2hrs Ole Oil 140°F 1125°F 2hrs

17

HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO 101515-L
PRINTED IN U.S.A.

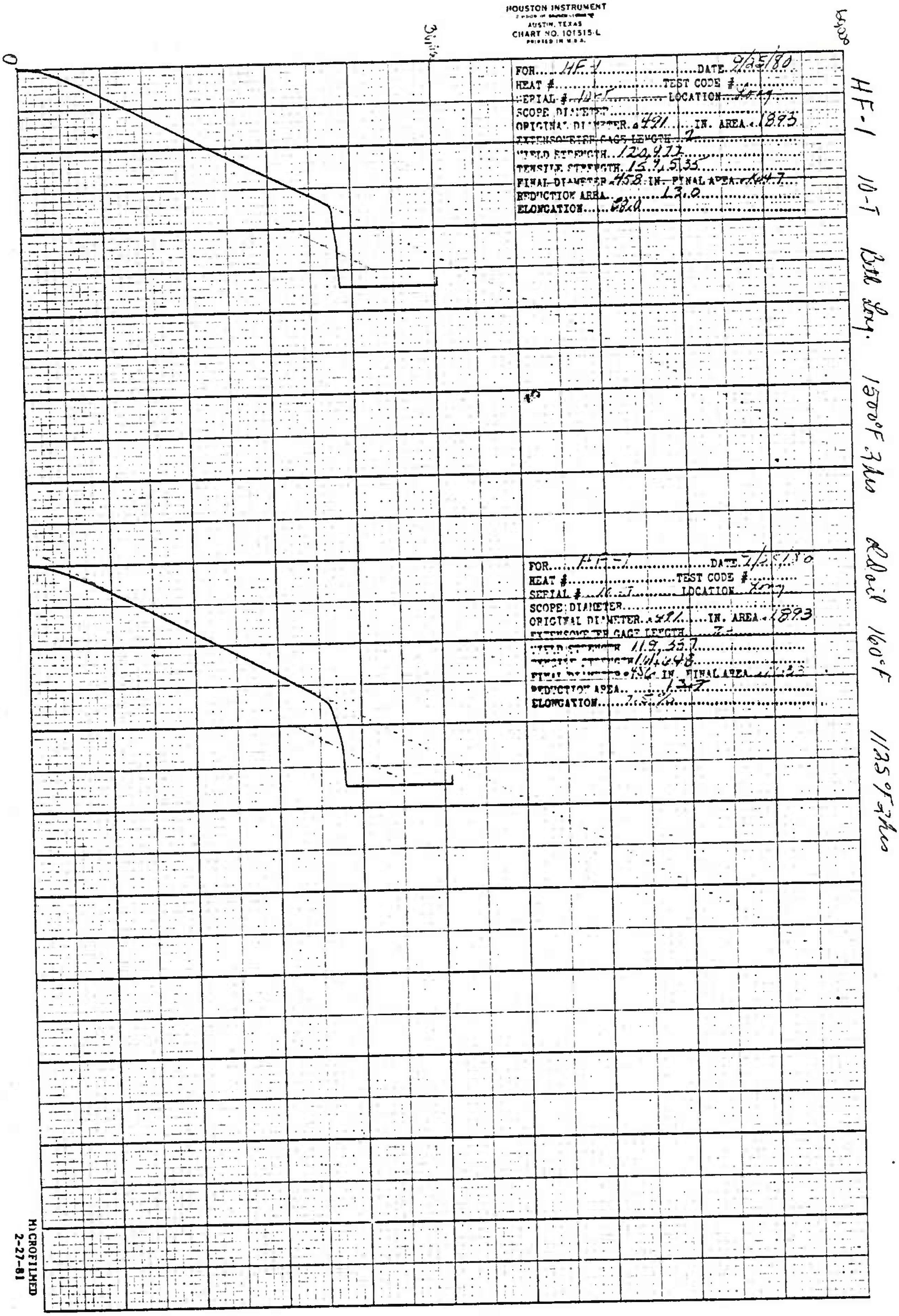
60,000 HF-1 2-X 1500°F 2hrs 150°F 1125°F 2hrs



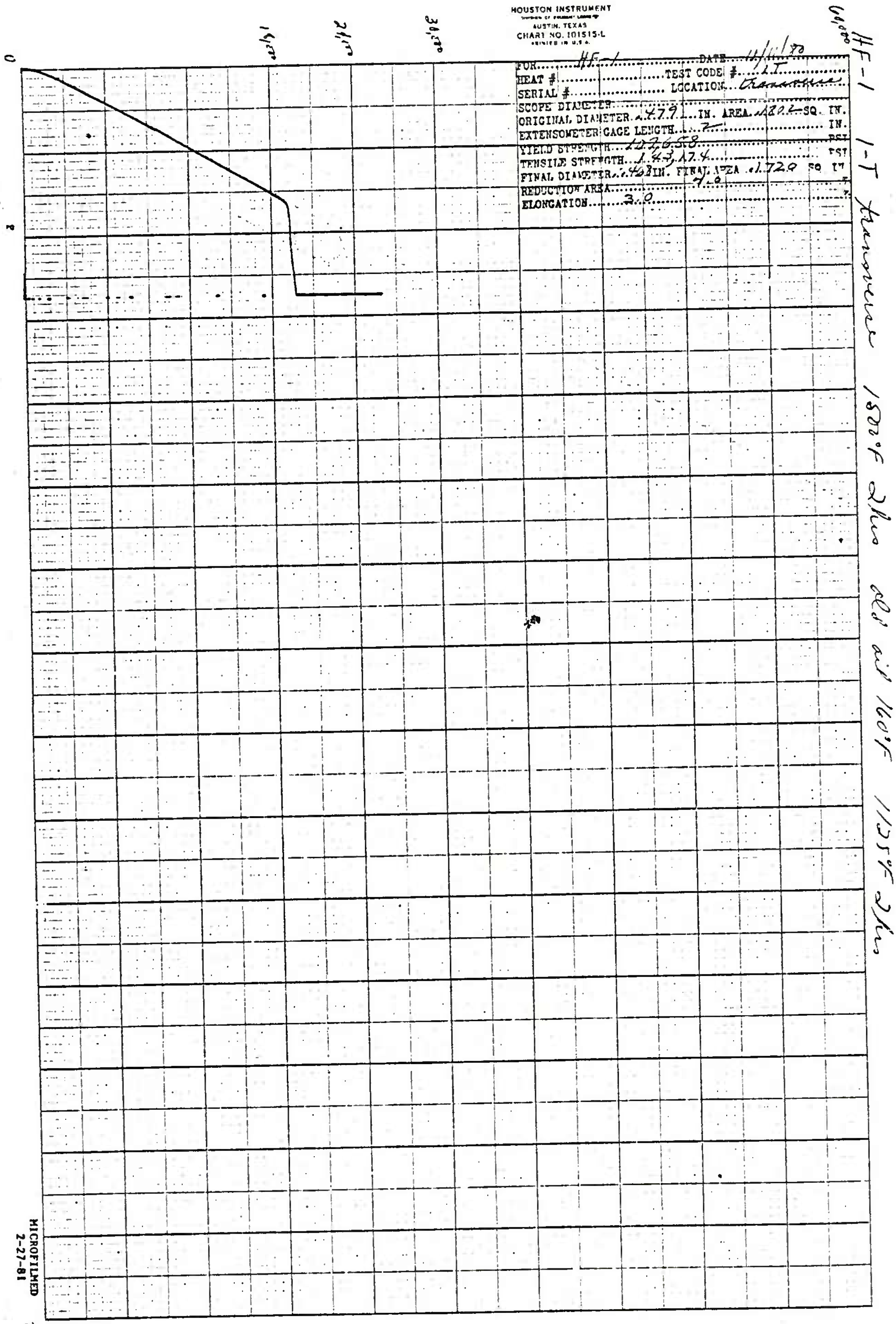
FOR HF-1 DATE 8/12/80
HEAT # TEST CODE #
SERIAL # 2-X LOCATION Long
SCOPE DIAMETER
ORIGINAL DIAMETER .503 IN. AREA .1987 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 115,752 PSI
TENSILE STRENGTH 160,040 PSI
FINAL DIAMETER .440 IN. FINAL AREA .1521 SQ. IN.
REDUCTION AREA 23.5 %
ELONGATION 12.0% %

MICROFILMED 2-27-81

18

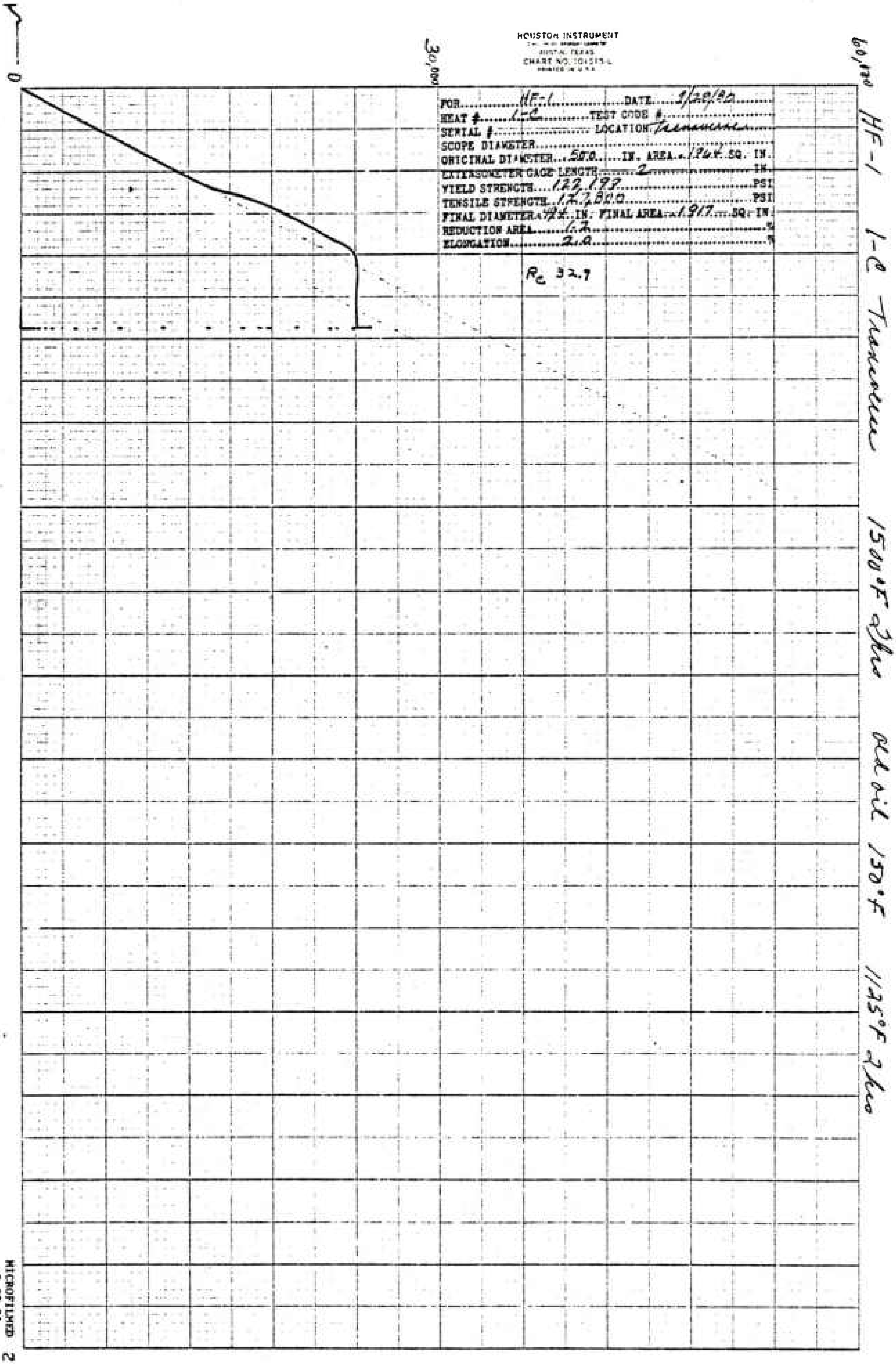


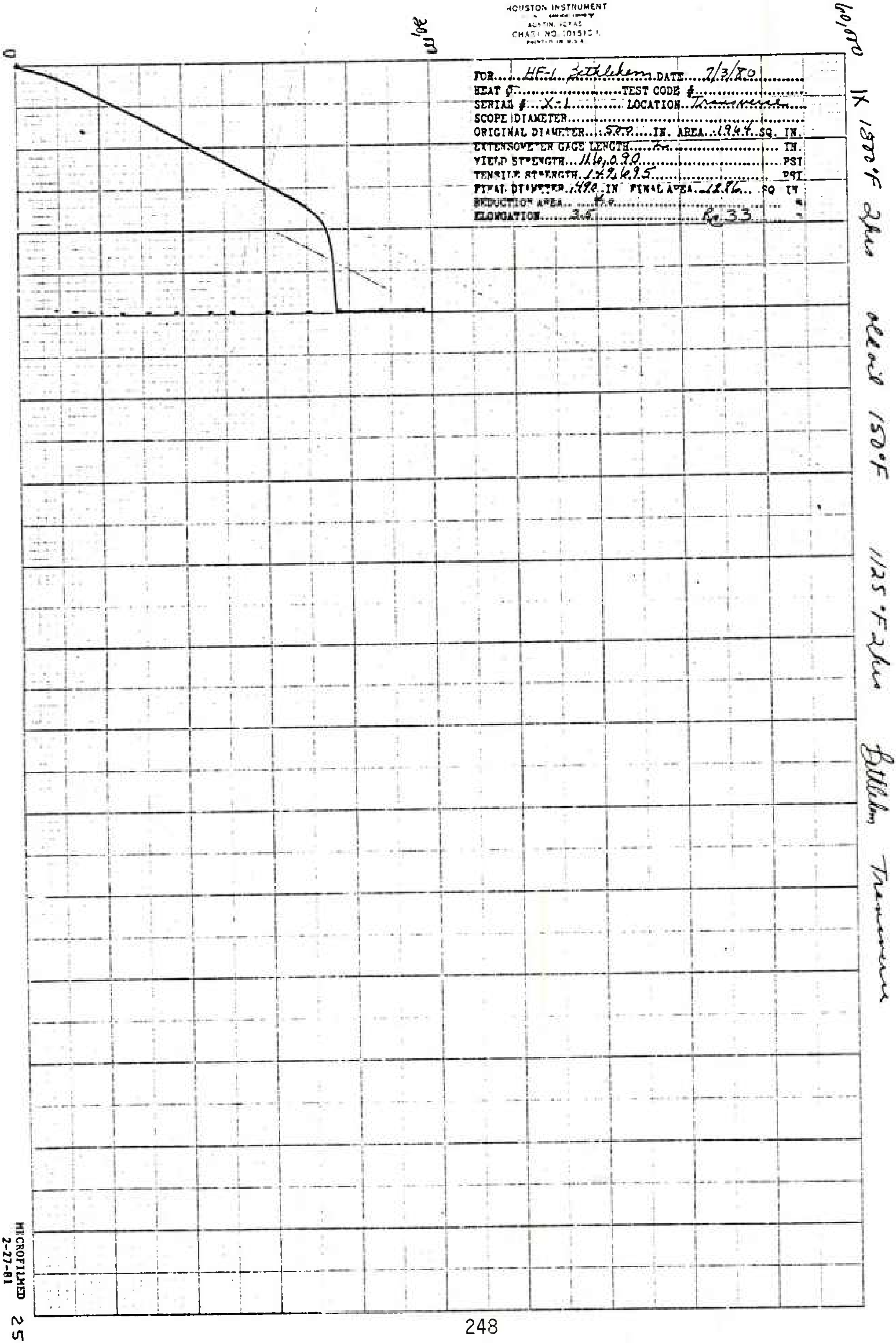
HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
FOR HF-1 DATE 9/25/80
HEAT # TEST CODE #
SERIAL # 10-T LOCATION Long
SCOPE DIAMETER
ORIGINAL DIAMETER .491 IN. AREA .1893
EXTENSOMETER GAGE LENGTH 2
YIELD STRENGTH 120,972
TENSILE STRENGTH 154,535
FINAL DIAMETER .458 IN. FINAL AREA .1647
REDUCTION AREA 13.0
ELONGATION
FOR DATE
HEAT # TEST CODE #
SERIAL # LOCATION
SCOPE DIAMETER
ORIGINAL DIAMETER IN. AREA .1893
EXTENSOMETER GAGE LENGTH
YIELD STRENGTH 119,357
TENSILE STRENGTH
FINAL DIAMETER IN. FINAL AREA
REDUCTION AREA
ELONGATION
HF-1 10-T Btm Long. 1500°F 3hr Rd oil 160°F 1125°F 7hr



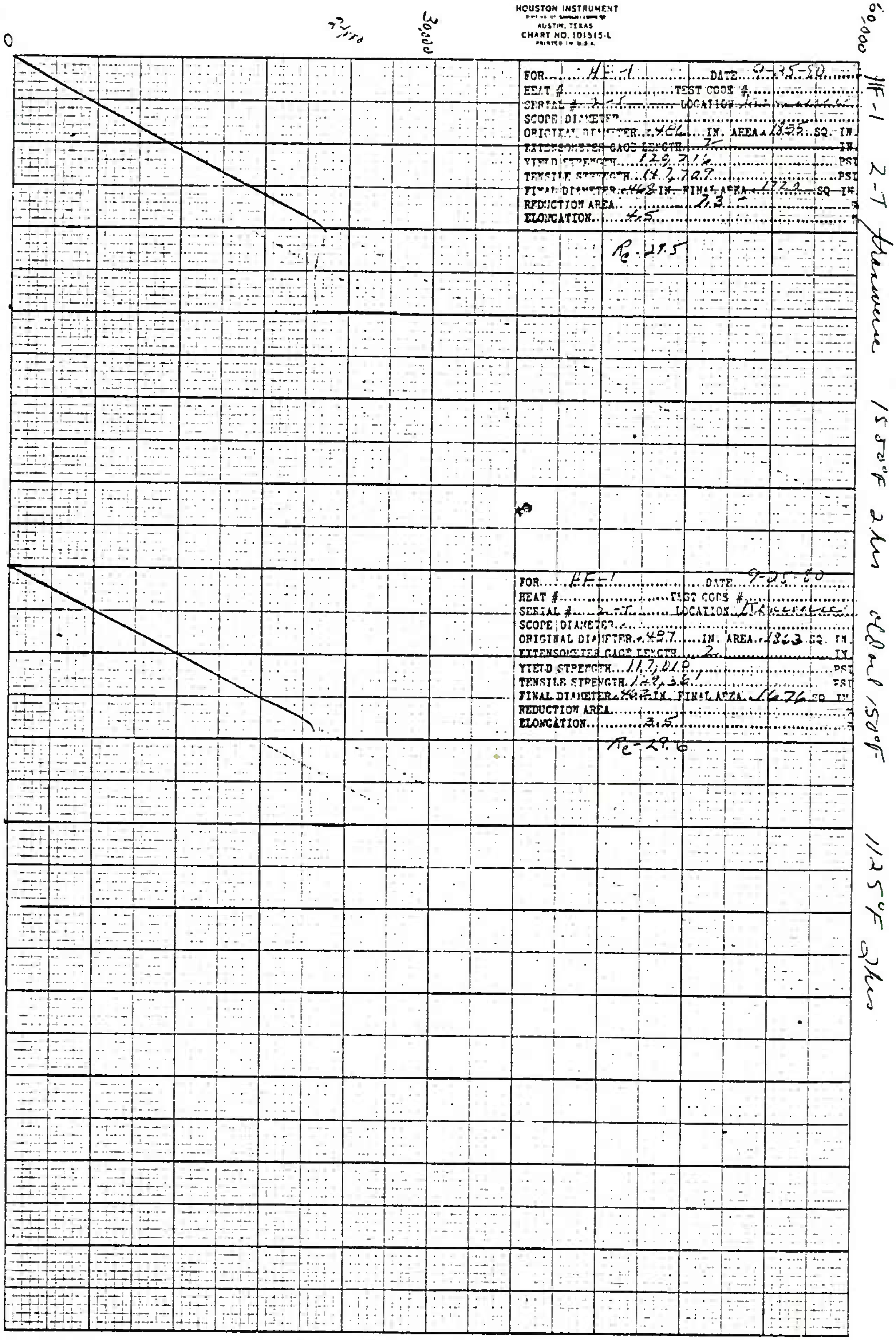
HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
FOR HF-1 DATE 11/11/80
HEAT # TEST CODE # 1T
SERIAL # LOCATION transverse
SCOPE DIAMETER
ORIGINAL DIAMETER .479 IN. AREA .1802 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 102,658 PSI
TENSILE STRENGTH 143,174 PSI
FINAL DIAMETER .468 IN. FINAL AREA .1720 SQ. IN.
REDUCTION AREA 4.0 %
ELONGATION 3.0 %
HF-1 1-T transverse 1500°F 2hrs
1135°F 2hrs

23

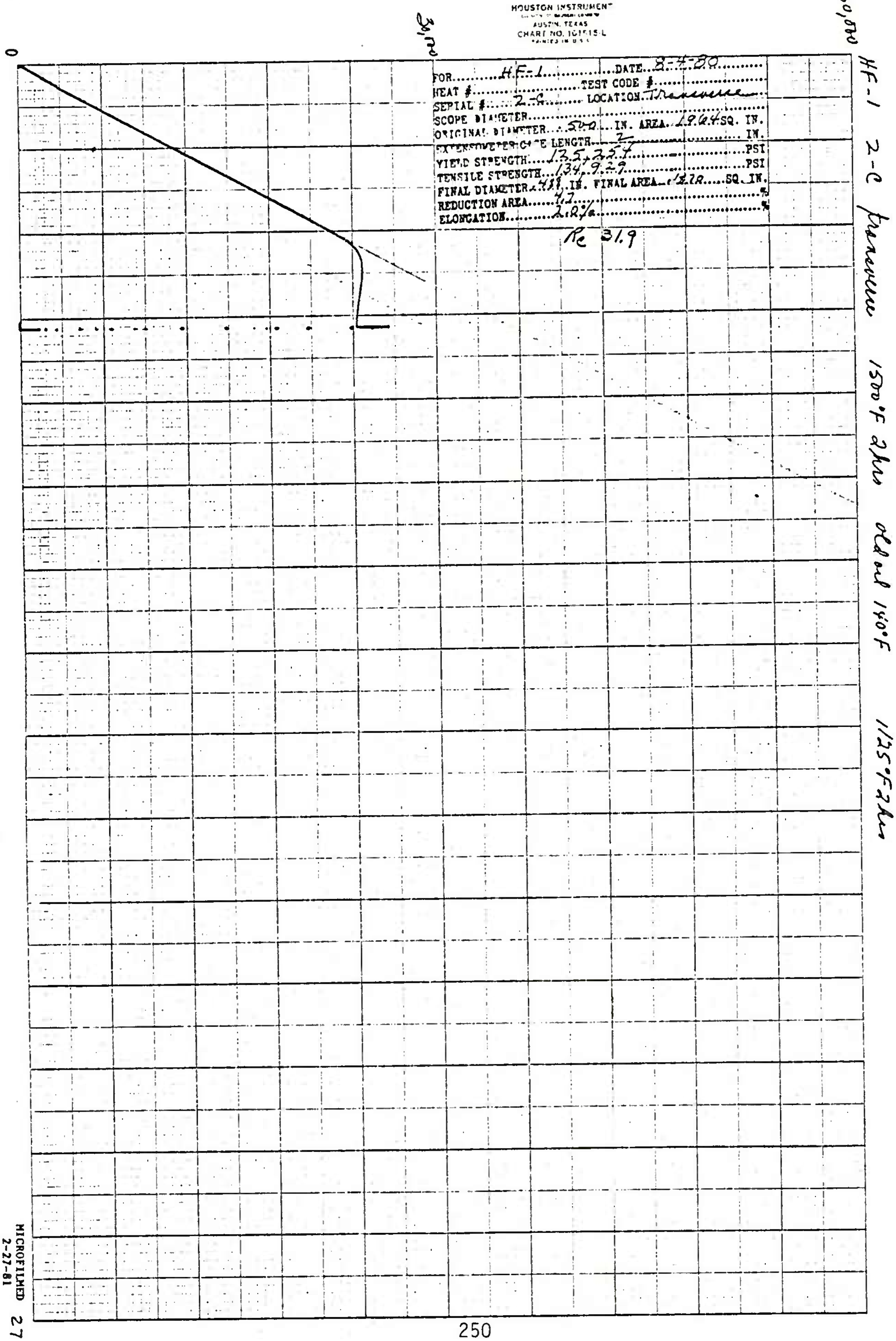

HOUSTON INSTRUMENT
CHART NO.
0
30,000
60,000
FOR HF-1 DATE 1/29/80
HEAT # 1-C TEST CODE #
SERIAL # LOCATION Transverse
SCOPE DIAMETER
ORIGINAL DIAMETER .500 IN. AREA .1964 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 122,197 PSI
TENSILE STRENGTH 127,800 PSI
FINAL DIAMETER .494 IN. FINAL AREA .1917 SQ. IN.
REDUCTION AREA 1.2 %
ELONGATION 2.0 %
R_c 32.7
HF-1 1-C Transverse 1500°F 2hrs Old oil 150°F 1125°F 2hrs



MICROFILMED 2-27-81 25

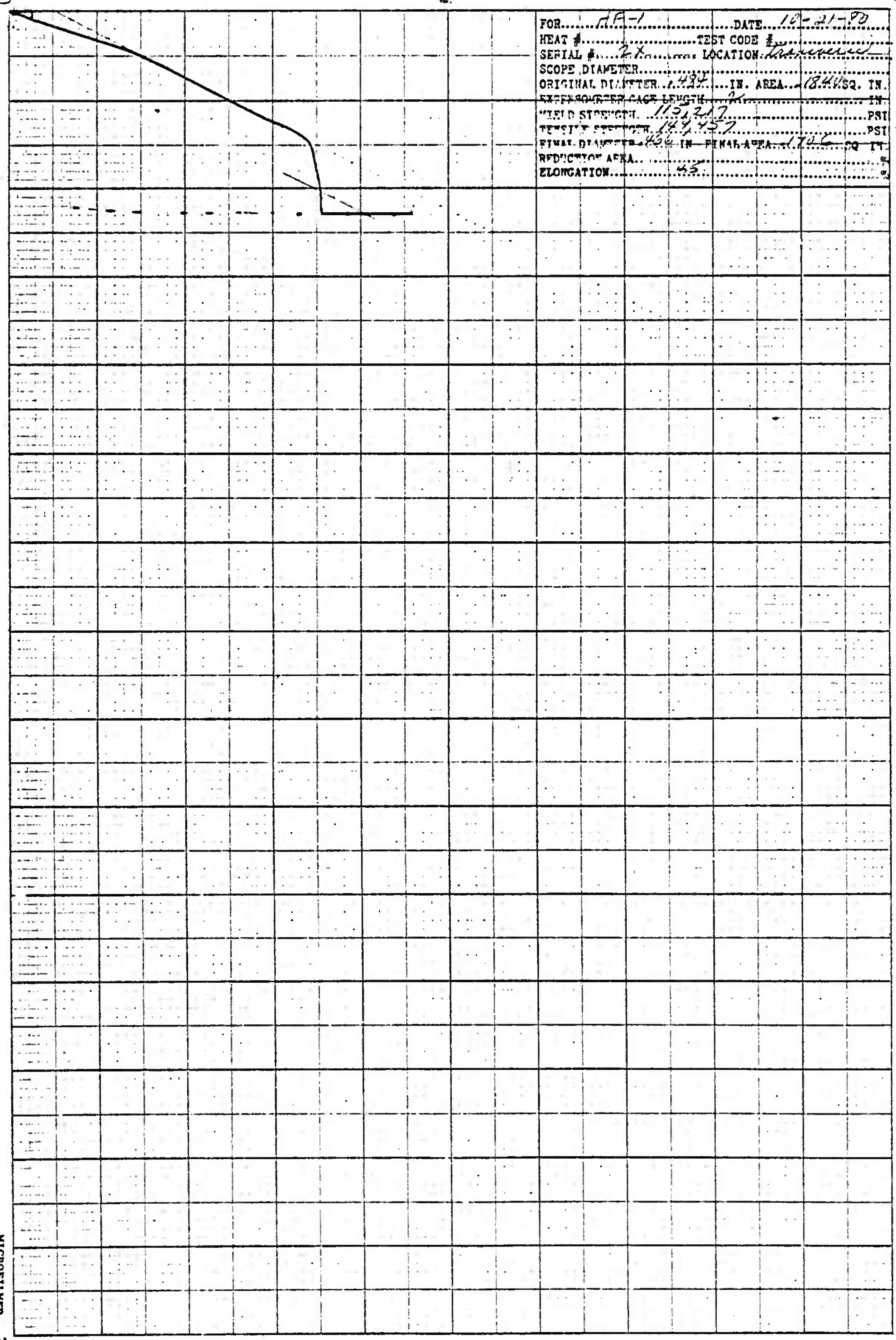


HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
PRINTED IN U.S.A.
0
30,000
60,000
FOR HF-1 DATE 9-25-80
HEAT # TEST CODE #
SERIAL # LOCATION
SCOPE DIAMETER
ORIGINAL DIAMETER .486 IN. AREA .1855 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 129,716 PSI
TENSILE STRENGTH 147,709 PSI
FINAL DIAMETER .468 IN. FINAL AREA .1720 SQ. IN.
REDUCTION AREA 7.3 %
ELONGATION 4.5 %
Rc-29.5
FOR HF-1 DATE 9-25-80
HEAT # TEST CODE #
SERIAL # LOCATION
SCOPE DIAMETER
ORIGINAL DIAMETER .487 IN. AREA .1863 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 117,010 PSI
TENSILE STRENGTH 149,361 PSI
FINAL DIAMETER .462 IN. FINAL AREA .1676 SQ. IN.
REDUCTION AREA %
ELONGATION 2.5 %
Rc-29.6
HF-1 2-T 1550°F 2 hrs 1125°F 2hrs



MICROFILMED 2-27-81 27

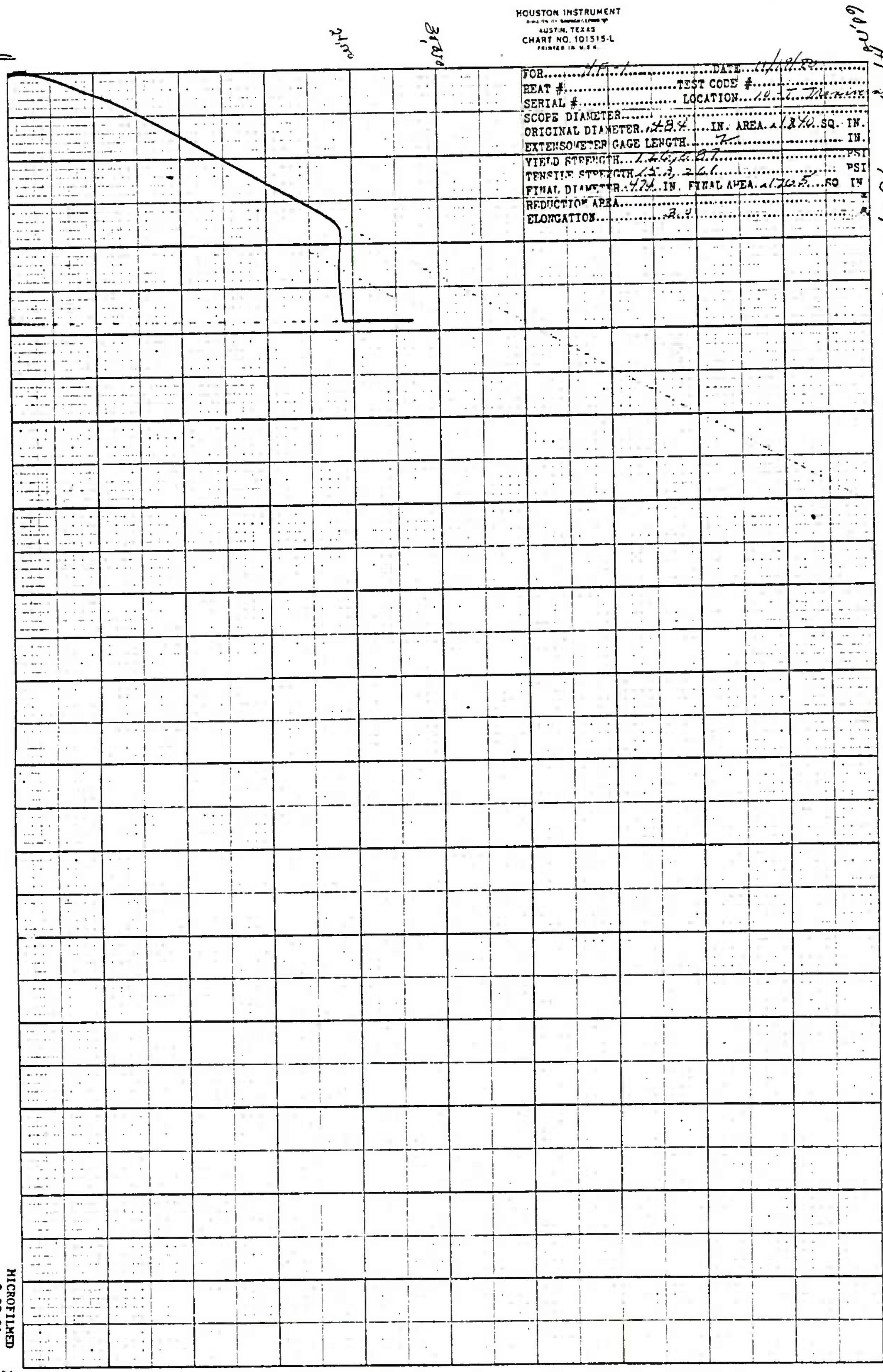
HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
PRINTED IN U.S.A.

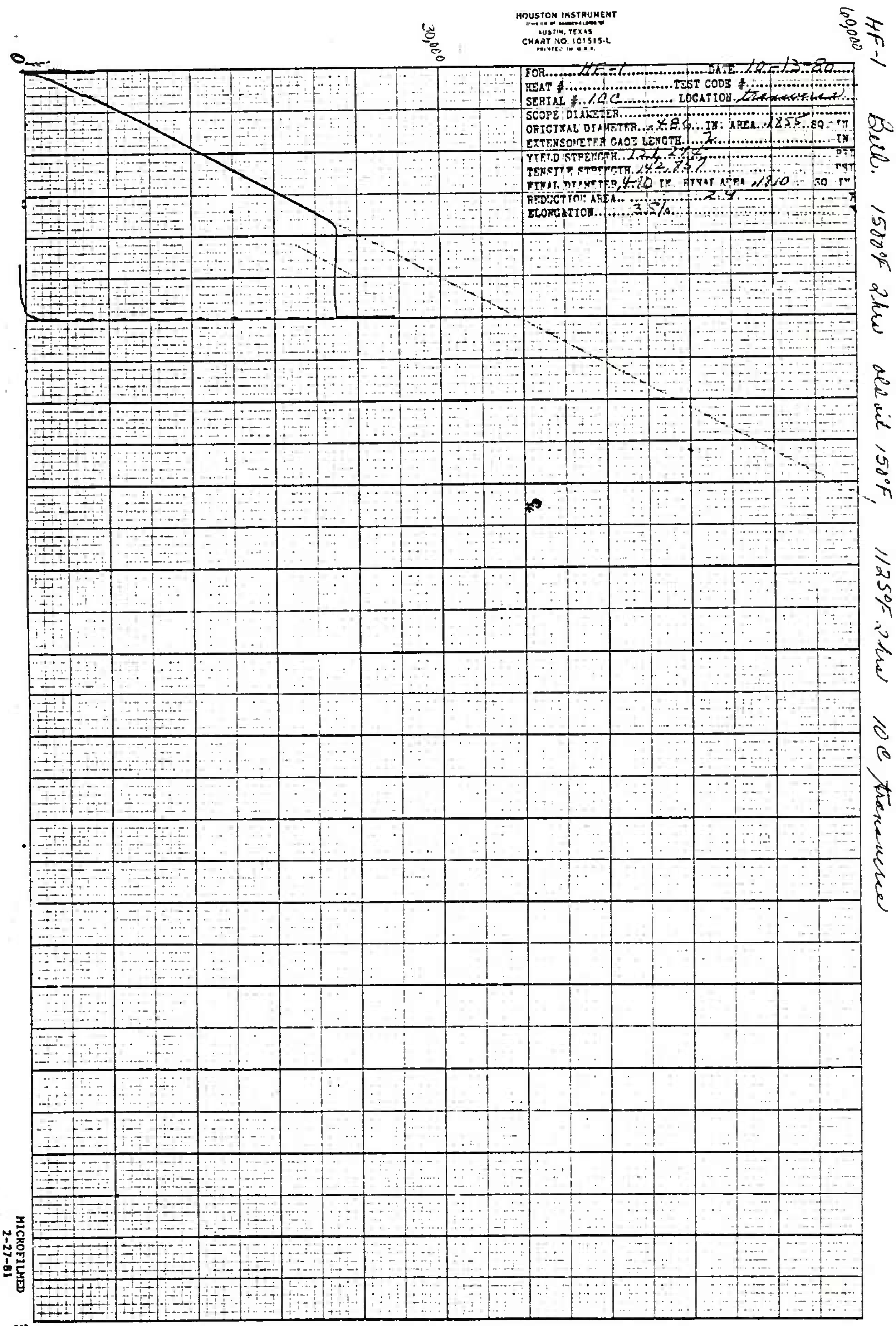


FOR HF-1 DATE 10-21-80
HEAT # TEST CODE #
SERIAL # 2X LOCATION transverse
SCOPE DIAMETER
ORIGINAL DIAMETER .484 IN. AREA .1844 SQ. IN.
EXTENSOMETER GAGE LENGTH 2" IN.
YIELD STRENGTH 115,217 PSI
TENSILE STRENGTH 144,457 PSI
FINAL DIAMETER .436 IN FINAL AREA .1706 SQ IN.
REDUCTION AREA %
ELONGATION 45 %

MICROFILMED 2-27-81

28


HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
PRINTED IN U.S.A.
FOR HF-1 DATE 11/18/80
HEAT # TEST CODE #
SERIAL # LOCATION 10-T
SCOPE DIAMETER
ORIGINAL DIAMETER .484 IN. AREA .1840 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 126,087 PSI
TENSILE STRENGTH 153,261 PSI
FINAL DIAMETER .471 IN. FINAL AREA .1705 SQ IN
REDUCTION AREA %
ELONGATION 3.4 %
HF-1
10-T
1300°F 3hrs
1125°F 3hrs


HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
30,000
60,000
0
FOR HE-1 DATE 10-13-80
HEAT # TEST CODE #
SERIAL # 10C LOCATION transverse
SCOPE DIAMETER
ORIGINAL DIAMETER .486 IN. AREA .1855 SQ. IN
EXTENSOMETER GAGE LENGTH 2 IN
YIELD STRENGTH 124,292 PSI
TENSILE STRENGTH 142,737 PSI
FINAL DIAMETER .480 IN. FINAL AREA .1810 SQ. IN
REDUCTION AREA 2.4 %
ELONGATION 3.5%
HF-1 Beth. 1500°F 2hrs oil 150°F, 1125°F 2hrs 10C transverse

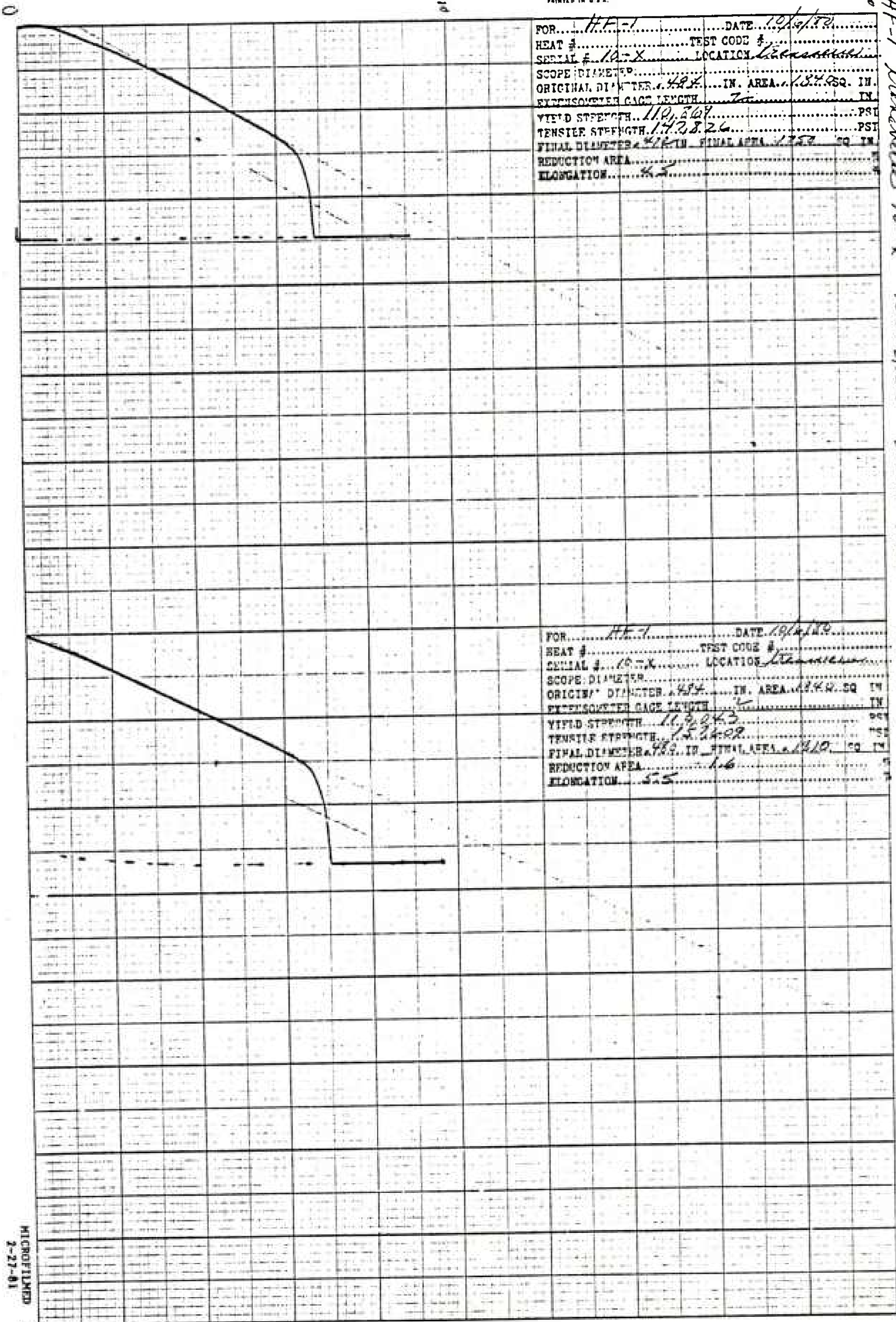
30

HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
PRINTED IN U.S.A.

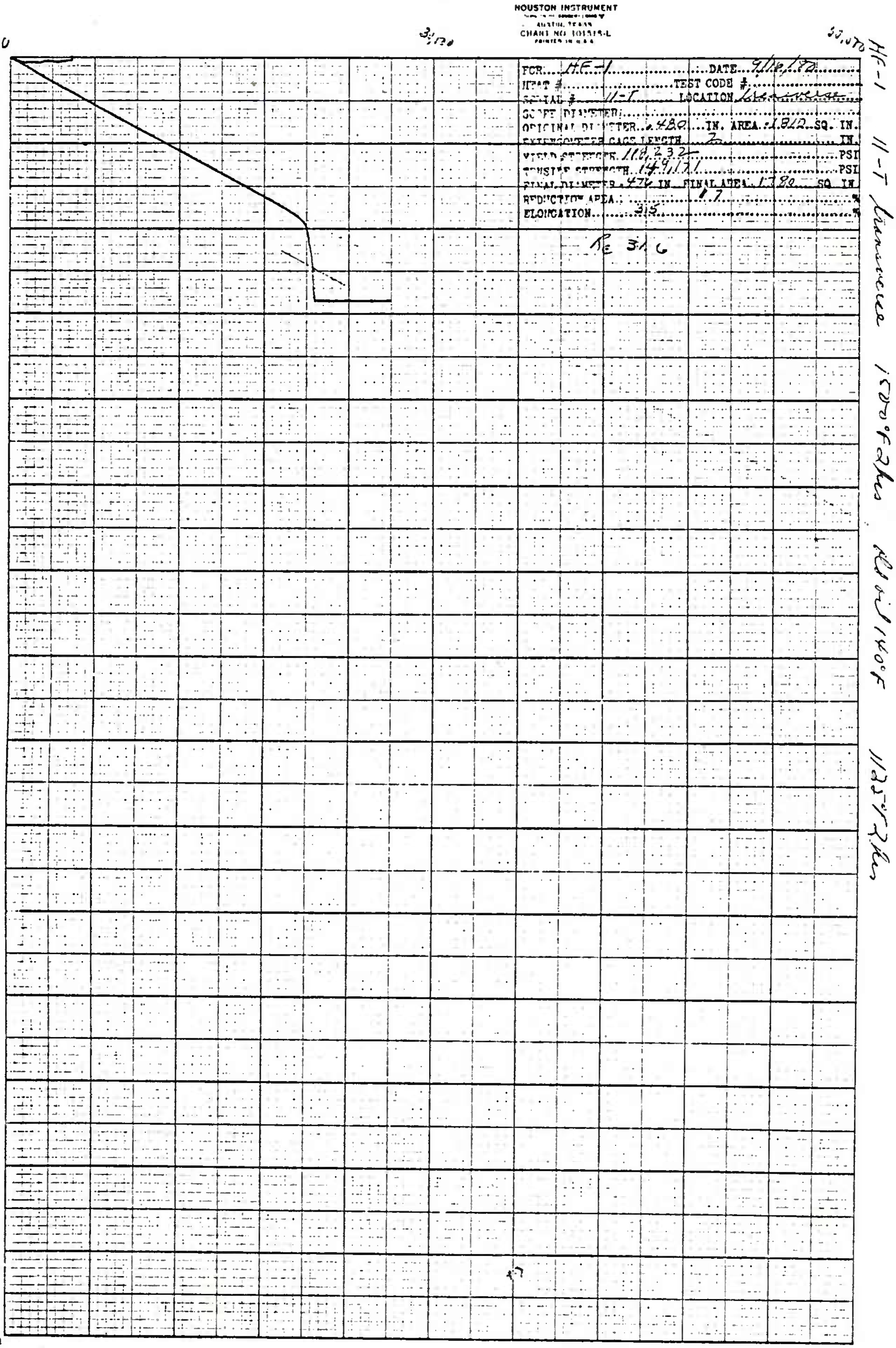
39,810

60,930

HF-1 10-X 140°F

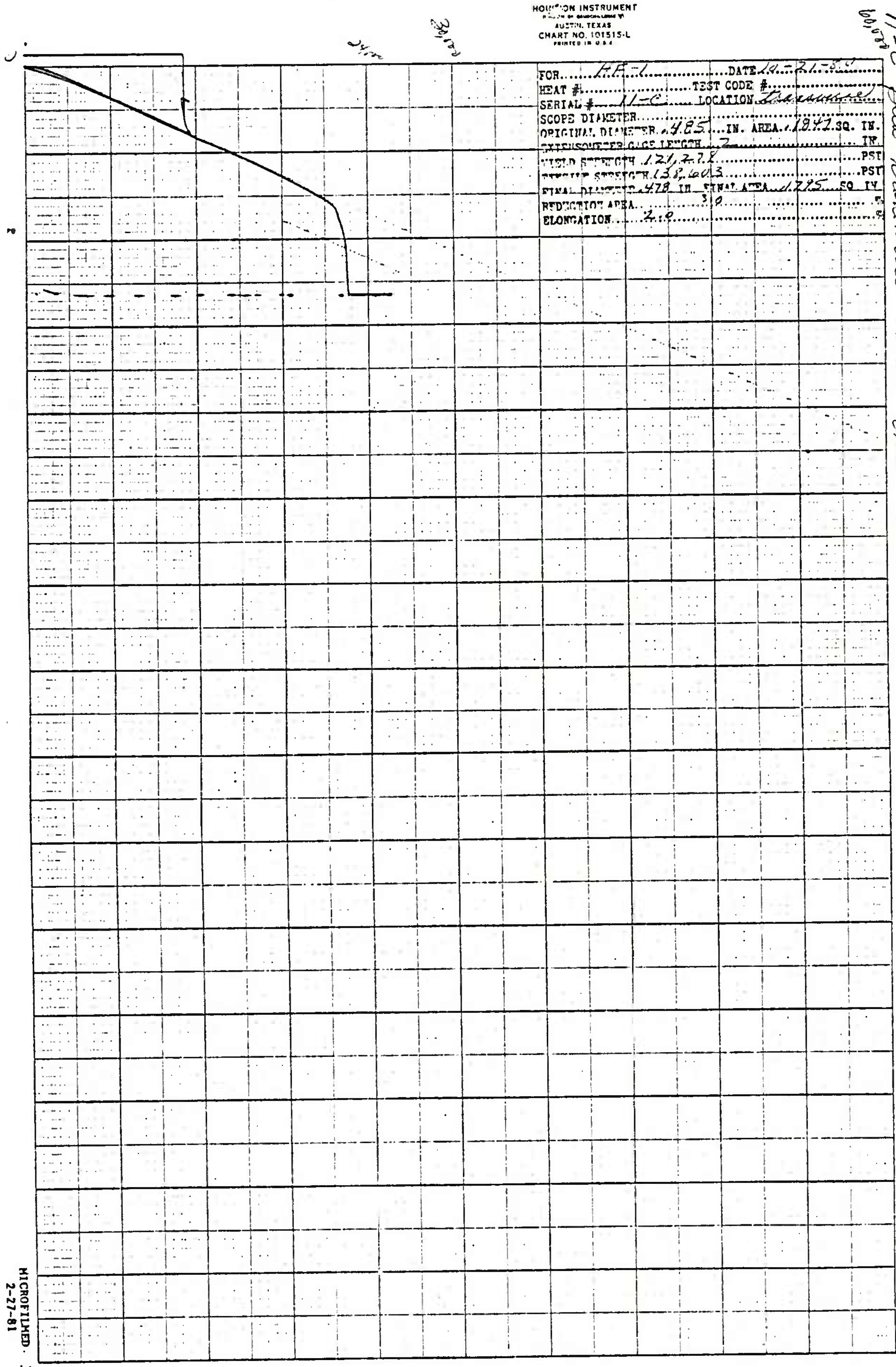


MICROFILMED
2-27-81



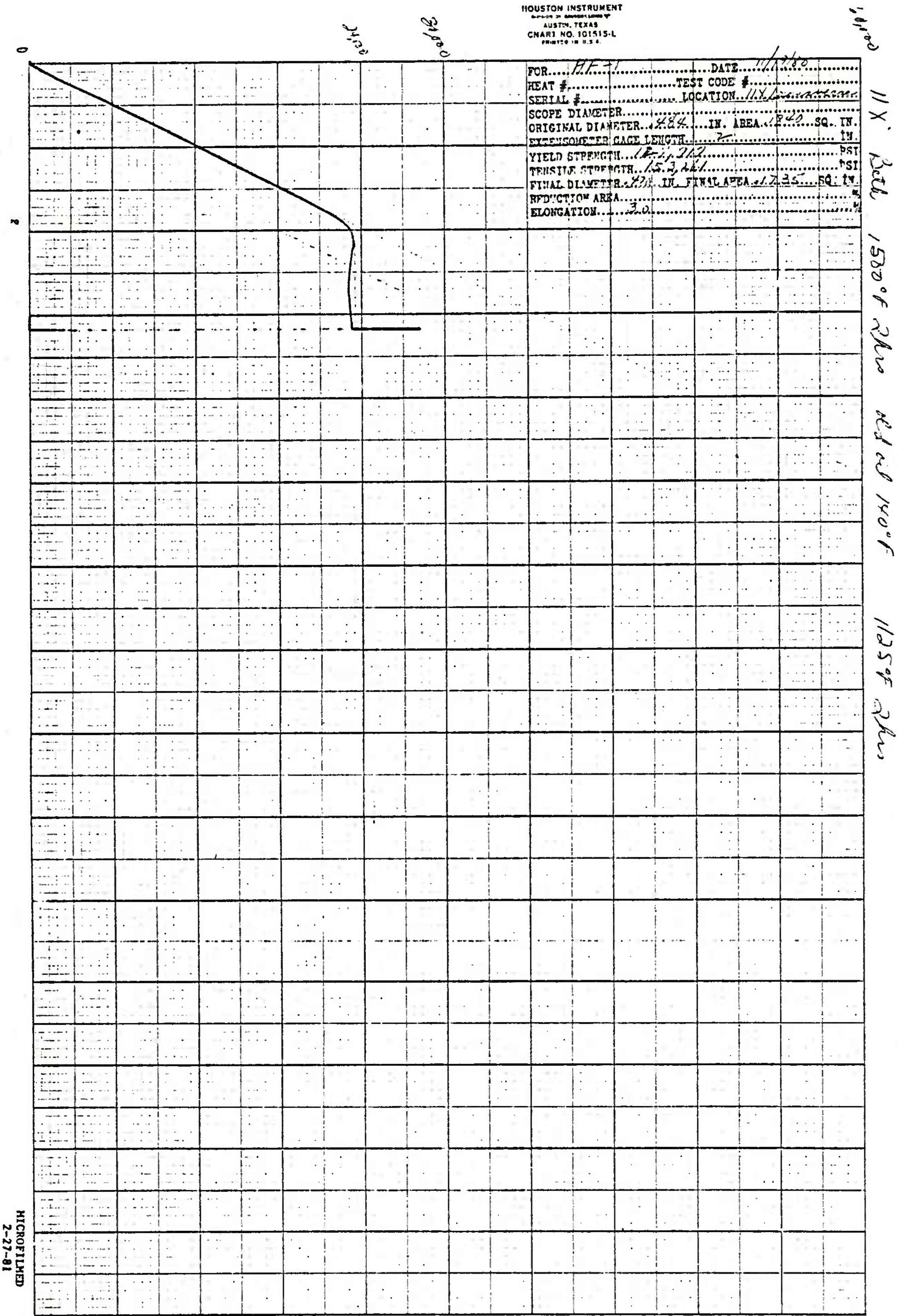
MICROFILMED 2-27-81

32



11-C 6th Transverse 1500°F 3hrs Hold 1500°F 1125°F 3hrs

60,000

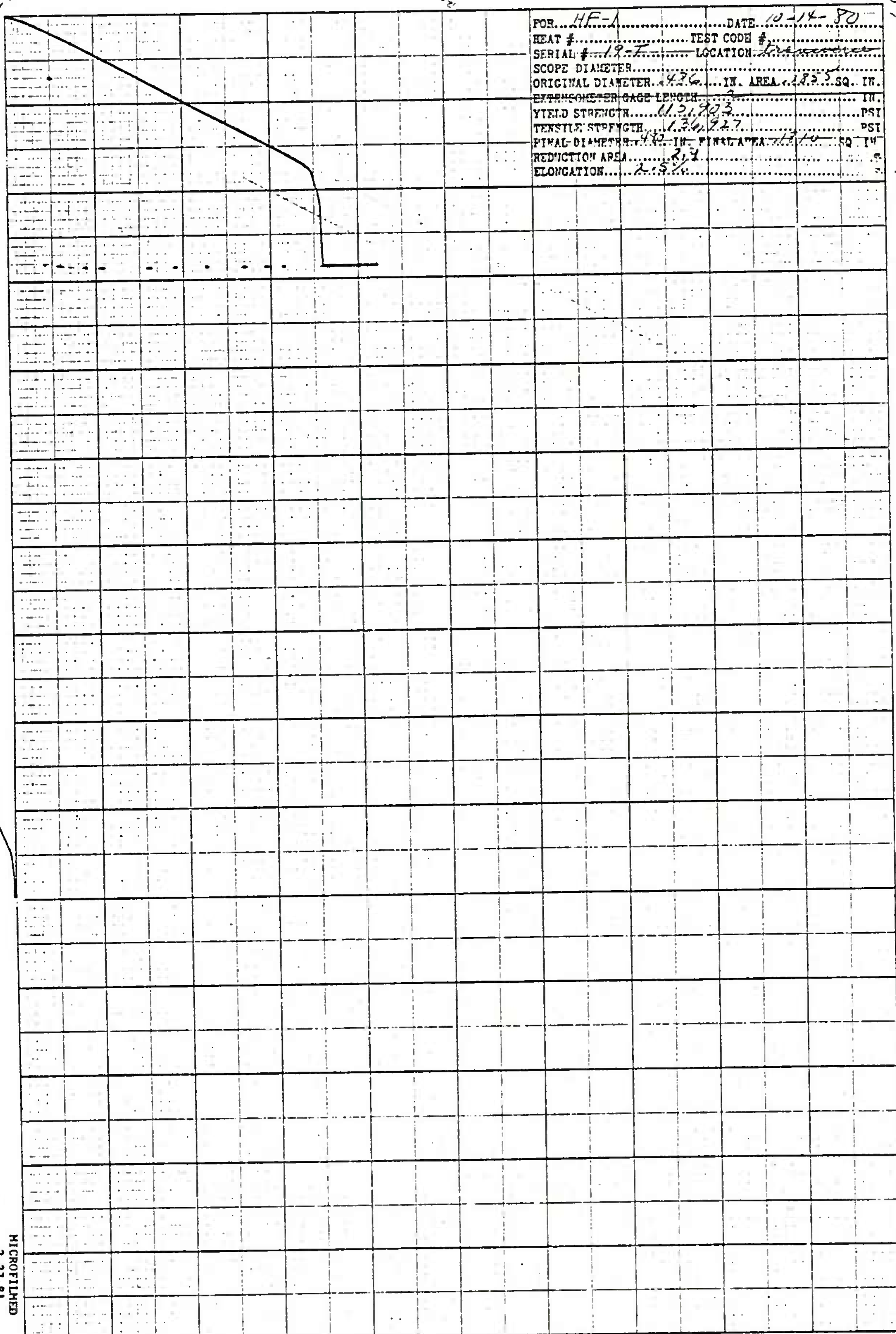


HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
PRINTED IN U.S.A.
0
2
4
FOR HF-1
DATE 11/7/80
HEAT #
TEST CODE #
SERIAL #
LOCATION 11X
SCOPE DIAMETER
ORIGINAL DIAMETER .484 IN. AREA .1840 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH PSI
TENSILE STRENGTH 153,221 PSI
FINAL DIAMETER IN. FINAL AREA .1735 SQ. IN.
REDUCTION AREA %
ELONGATION 3.0 %
11X' Bath 1500°F 2hrs Held at 1400°F 1125°F 2hrs

34

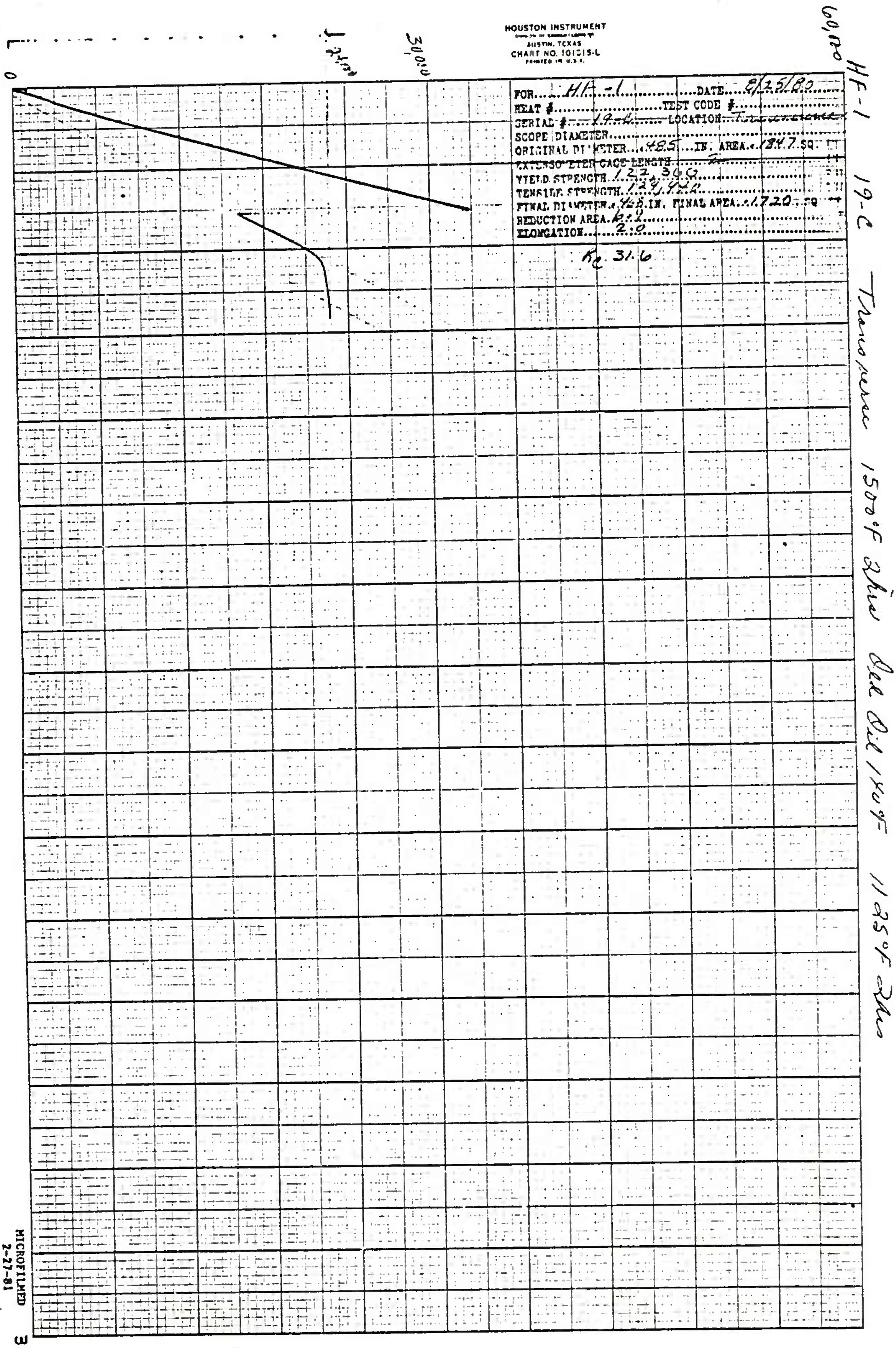
HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
PRINTED IN U.S.A.

19-T, transverse 1500° 2hrs oil 150°F 1125°F 2hrs
6000



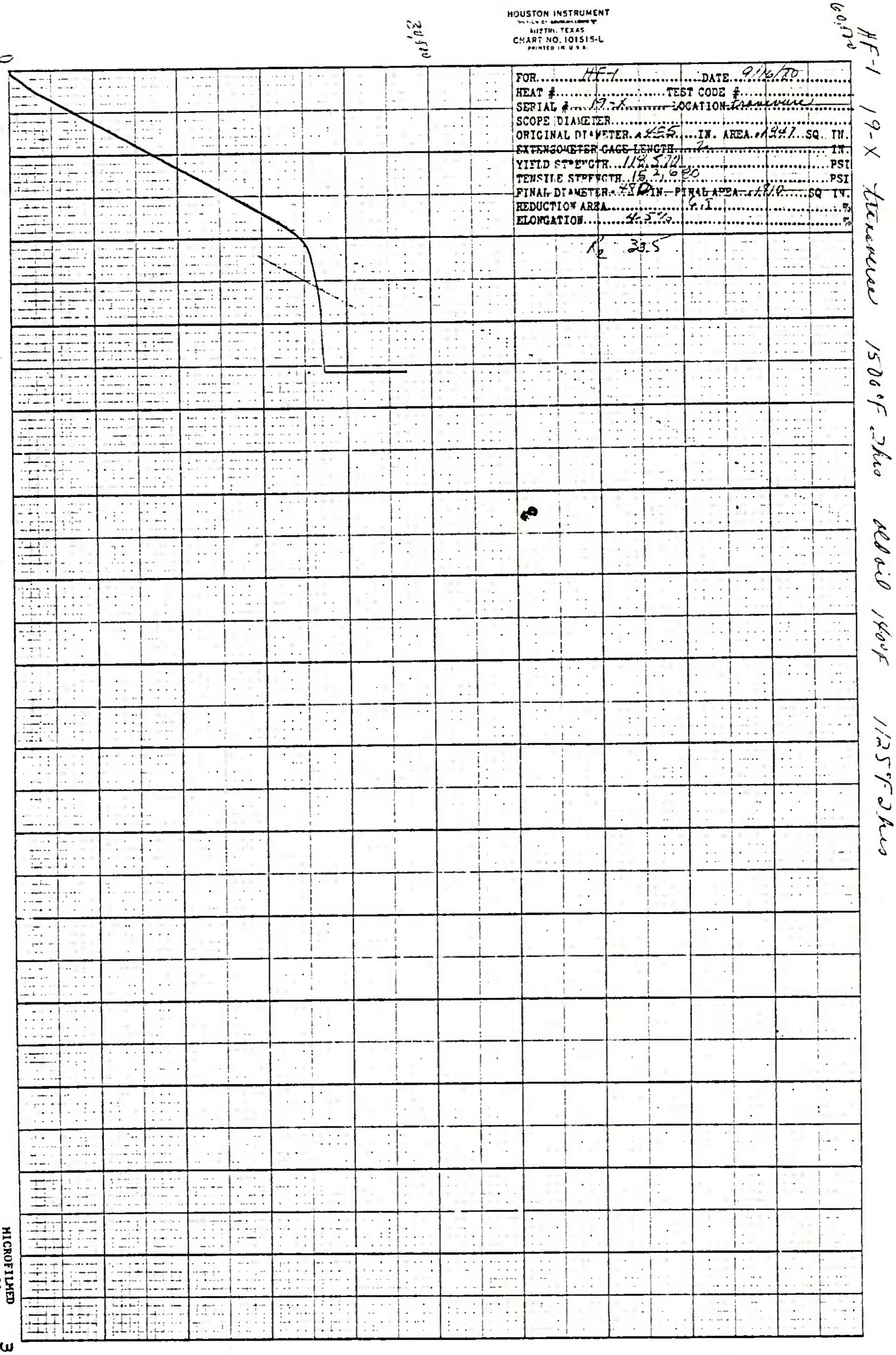
MICROFILMED
2-27-81

35



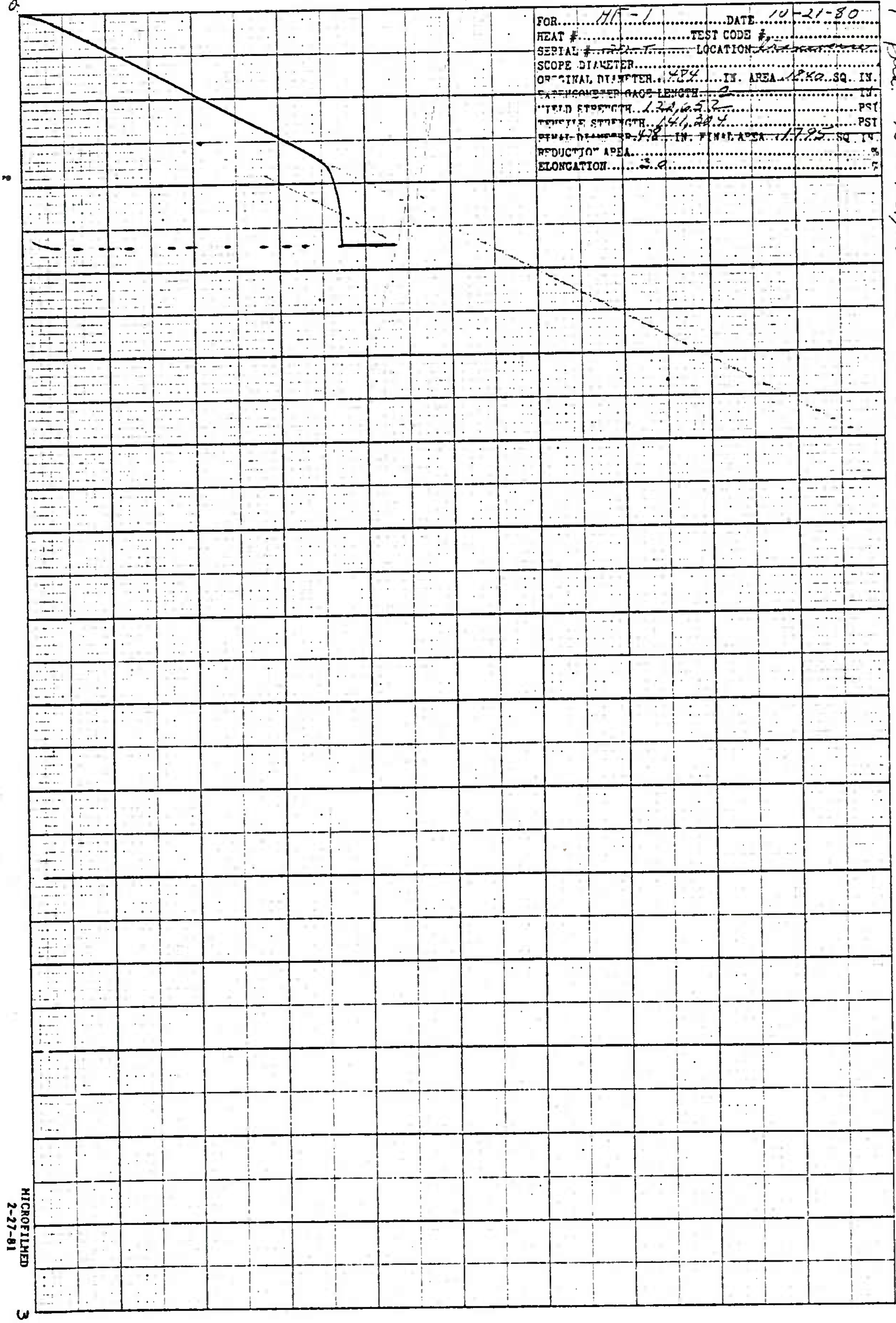
MICROFILMED 2-27-81

36


HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
PRINTED IN U.S.A.
0
30,000
60,000
FOR HF-1 DATE 9/16/80
HEAT # TEST CODE #
SERIAL # 19-X LOCATION transverse
SCOPE DIAMETER
ORIGINAL DIAMETER .455 IN. AREA .1847 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 118,570 PSI
TENSILE STRENGTH 152,680 PSI
FINAL DIAMETER .480 IN. FINAL AREA .1810 SQ IN.
REDUCTION AREA 6.1 %
ELONGATION 4.5% %
R_c 33.5
HF-1 19-X transverse 1500°F 2hrs oil 1400°F 1125°F 2hrs

37

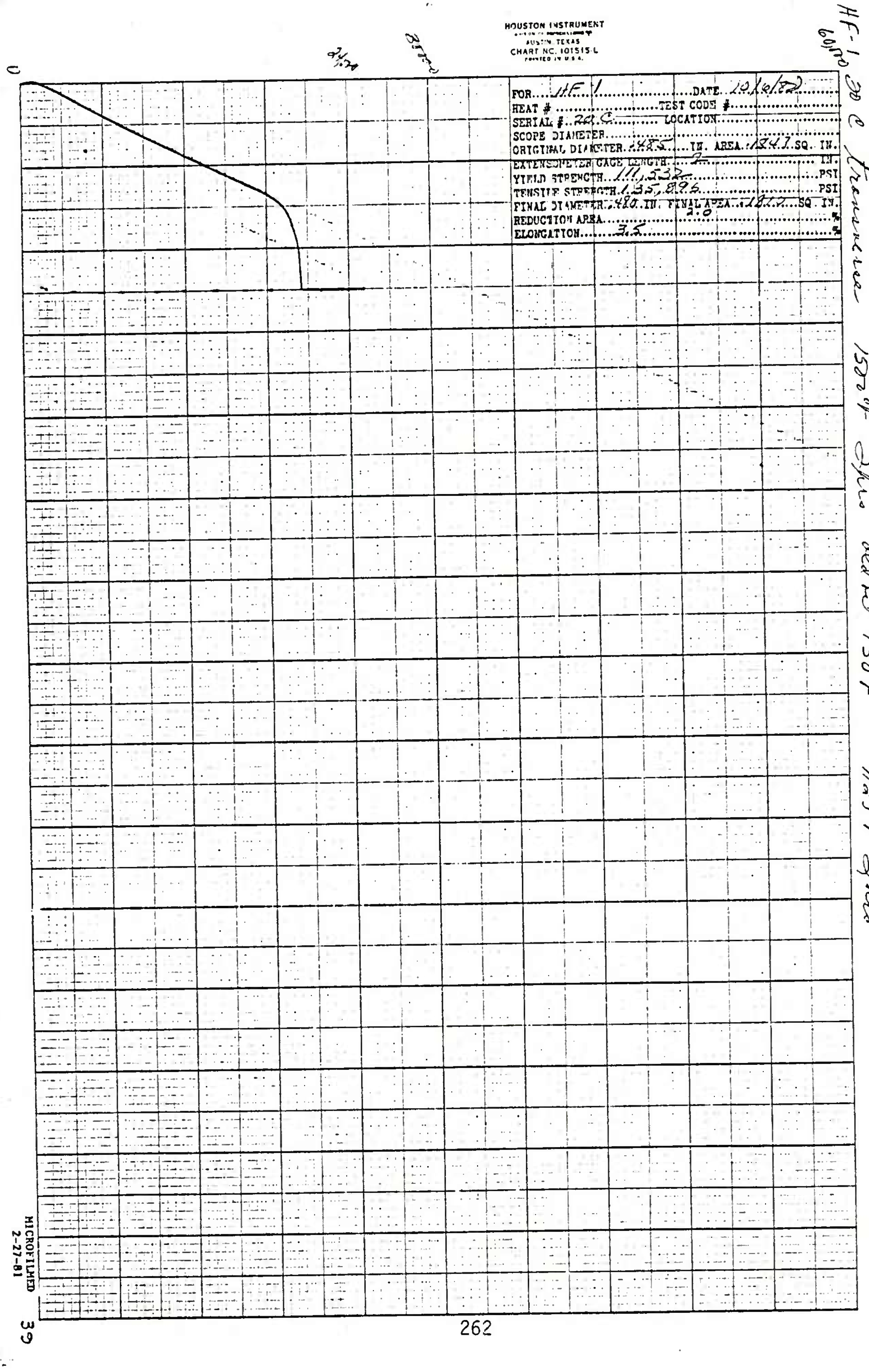
HOUSTON INSTRUMENT
AUSTIN TEXAS
CHART NO. 1U1515-L
PRINTED IN U.S.A.



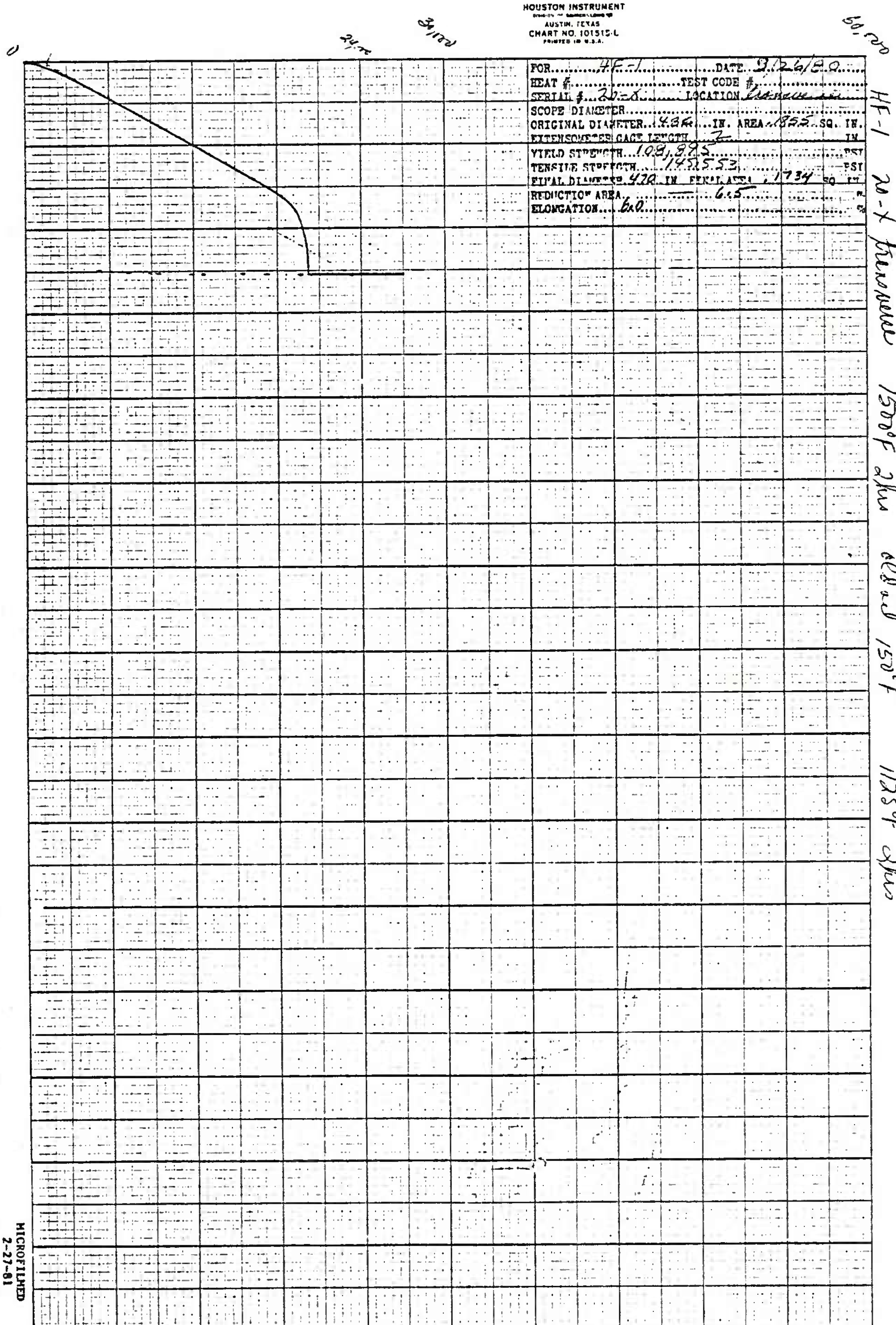
2QT 600 Btl. 1500°F 2hr Oil 150°F 1125°F

MICROFILMED
2-27-81

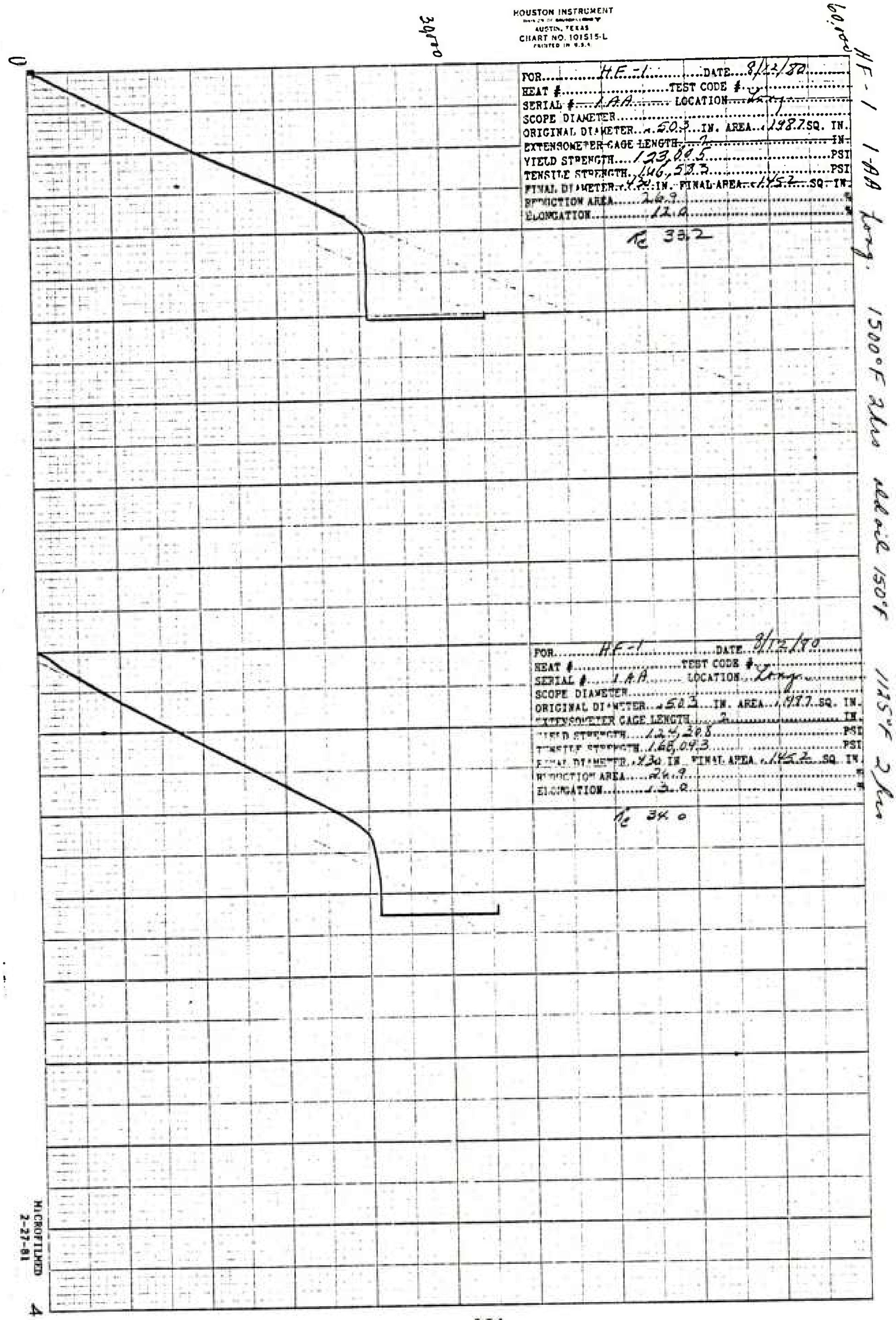
38



HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
PRINTED IN U.S.A.
FOR HF-1 DATE 10/6/82
HEAT # TEST CODE #
SERIAL # 20-C LOCATION
SCOPE DIAMETER
ORIGINAL DIAMETER .485 IN. AREA .1847 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 111,532 PSI
TENSILE STRENGTH 135,896 PSI
FINAL DIAMETER .480 IN. FINAL AREA .1810 SQ. IN.
REDUCTION AREA 2.0 %
ELONGATION 3.5 %
HF-1
60,000
1500°F 2hrs
1500°F
1125°F 2hrs
0
39



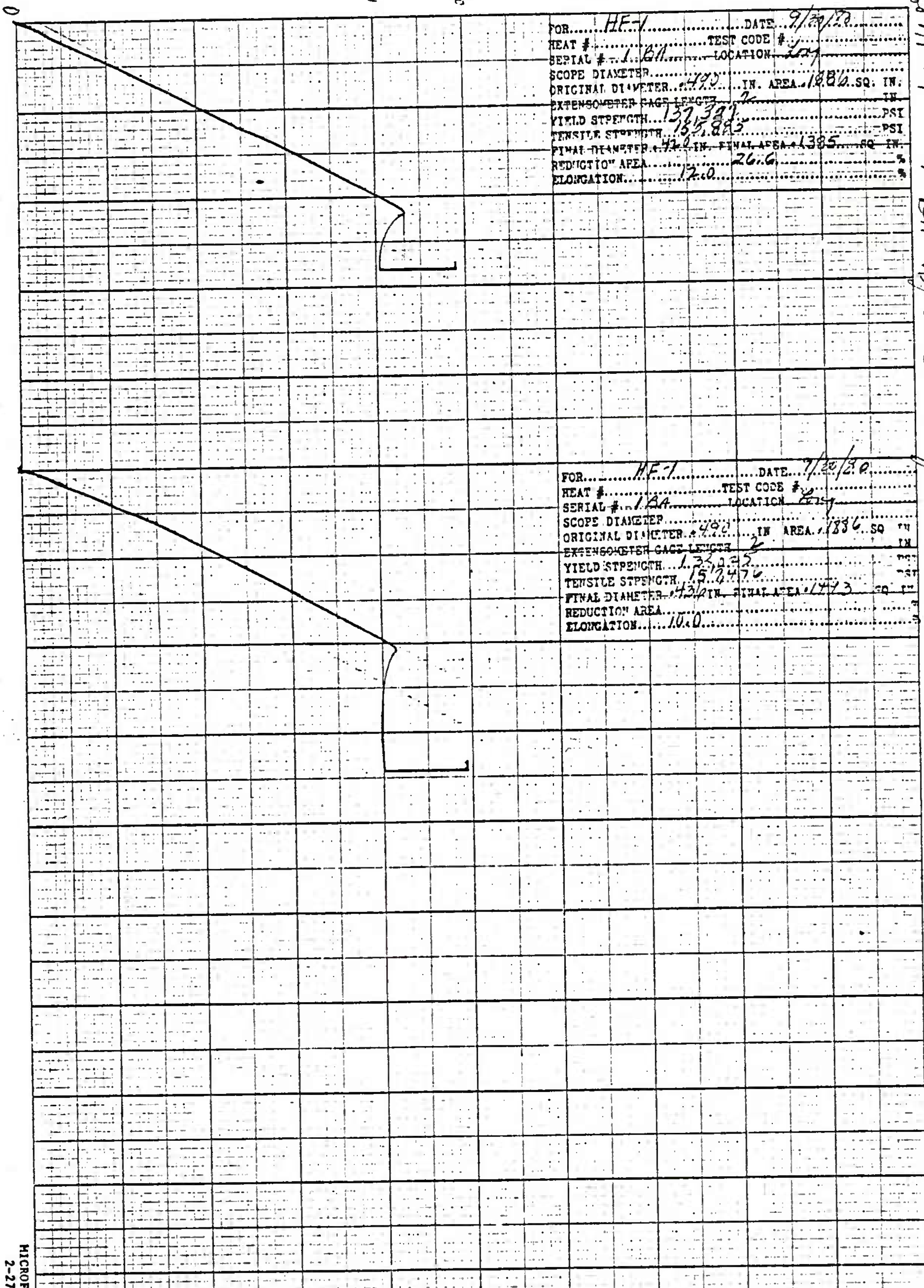
MICROFILMED
2-27-81
40


HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
PRINTED IN U.S.A.
0
30,000
60,000
HF-1 1-AA Long. 1500°F 2hrs oil 150°F 1125°F 2hrs
FOR H.E.-1 DATE 8/22/80
HEAT #
TEST CODE #
SERIAL # 1AA
LOCATION Long
SCOPE DIAMETER
ORIGINAL DIAMETER .503 IN. AREA .1987 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 123,805 PSI
TENSILE STRENGTH 146,533 PSI
FINAL DIAMETER .430 IN. FINAL AREA .1452 SQ. IN.
REDUCTION AREA 26.9 %
ELONGATION 12.0 %
Rc 33.2
FOR HE-1 DATE 8/22/80
HEAT #
TEST CODE #
SERIAL # 1AA
LOCATION Long
SCOPE DIAMETER
ORIGINAL DIAMETER .503 IN. AREA .1987 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 124,308 PSI
TENSILE STRENGTH 146,093 PSI
FINAL DIAMETER .430 IN. FINAL AREA .1452 SQ. IN.
REDUCTION AREA 26.9 %
ELONGATION 13.0 %
Rc 34.0

4

HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101315-L
PRINTED IN U.S.A.

24,000 36,000 60,000

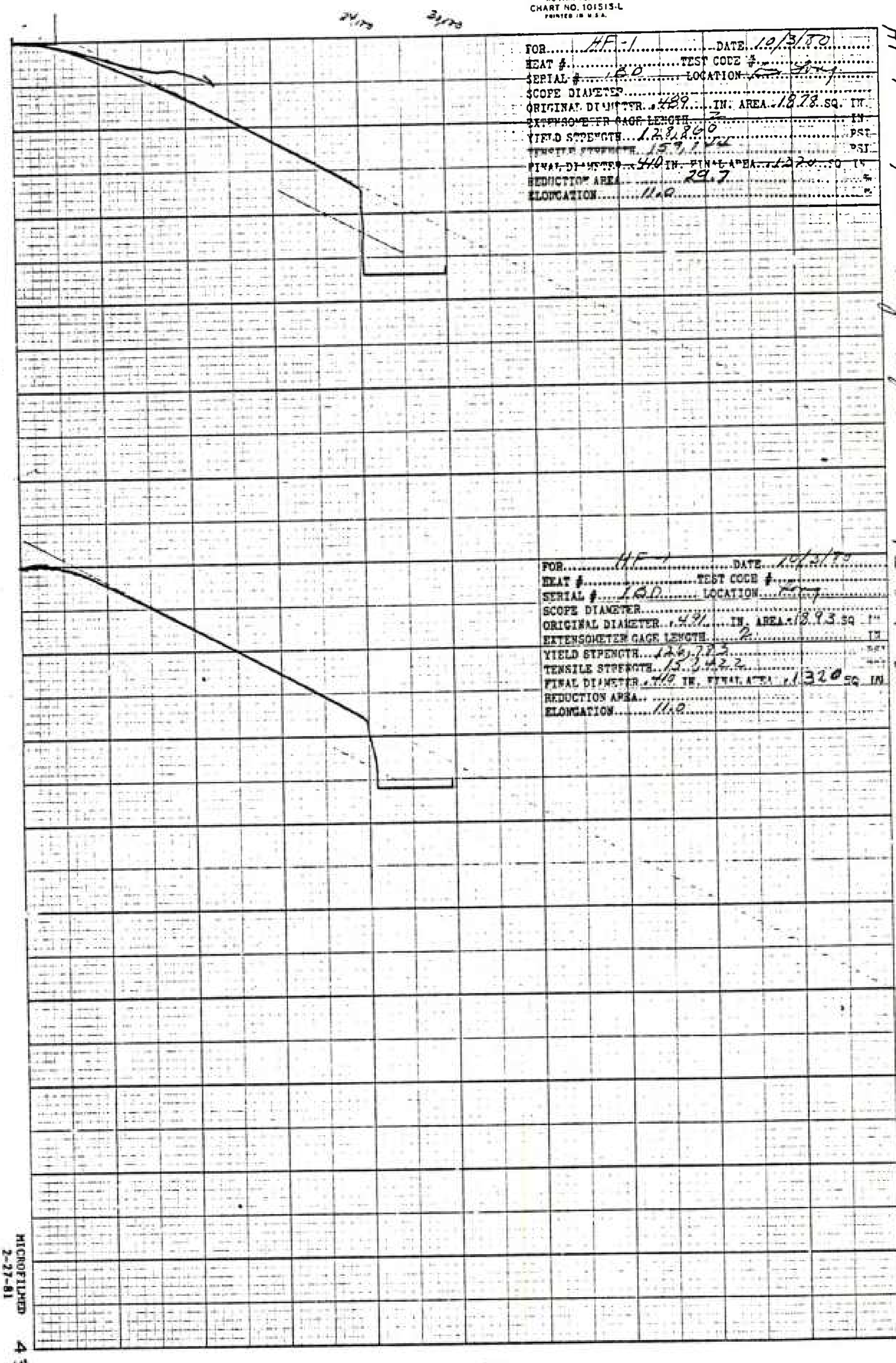


HF-1 1-BA Republic Long 1550°F 2hr oil quench 160°F 1125°F 2hrs

MICROFILMED
2-27-81

42

HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
PRINTED IN U.S.A.

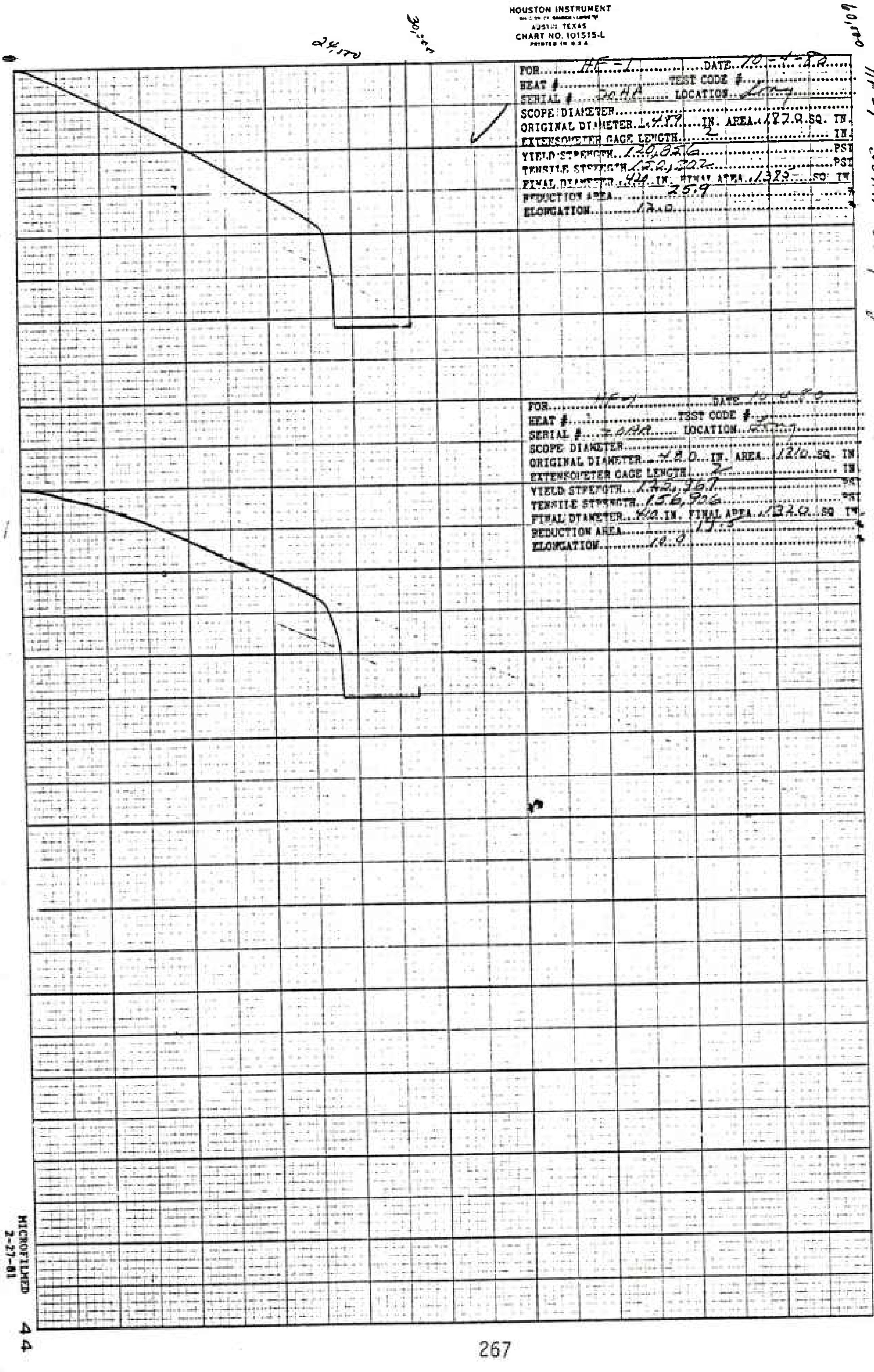


HF-1 1BD Long Republic 1500°F 2hrs [illegible] 1160°F 1135°F 2hrs

MICROFILMED 2-27-81

43

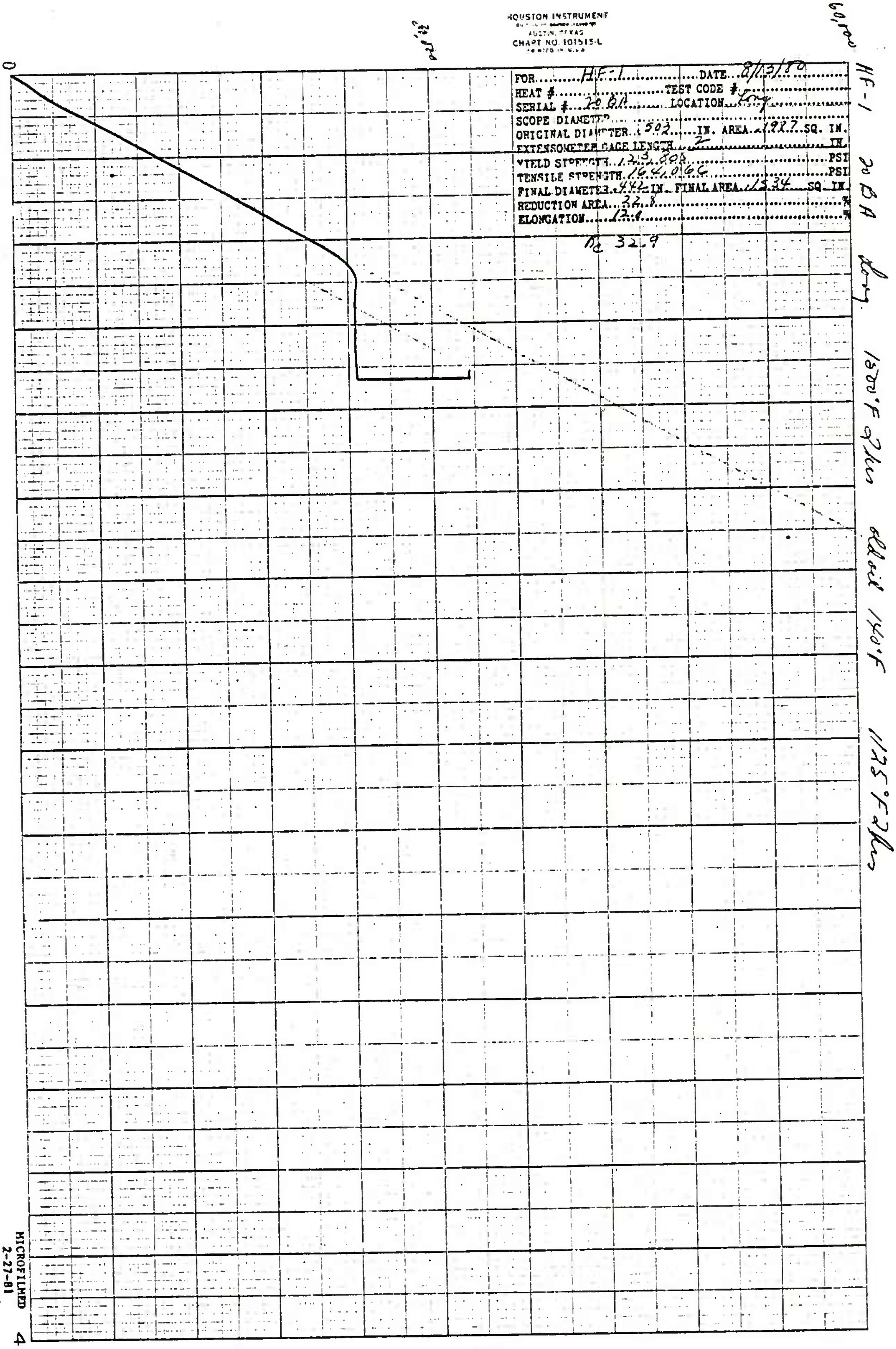
HOUSTON INSTRUMENT
AUSTIN TEXAS
CHART NO. 101515-L
PRINTED IN U.S.A.



HF-1 20AA Long Republic 1500°F 2hrs Oiled 1600°F 1125°F 2hrs

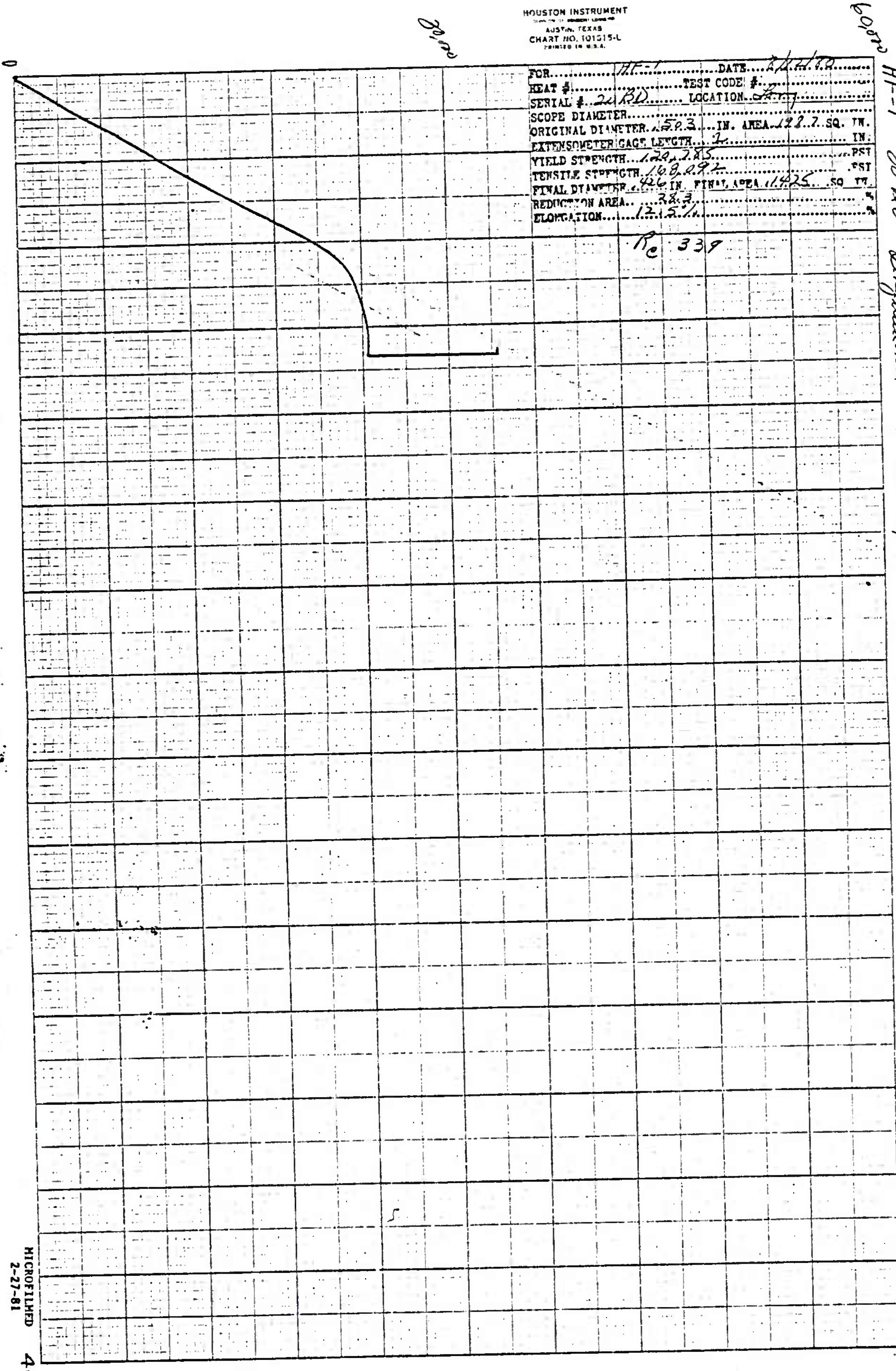
MICROFILMED 2-27-81

44



HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
0
60,000
FOR HF-1 DATE 8/13/80
HEAT # TEST CODE #
SERIAL # 20 BA LOCATION Long
SCOPE DIAMETER
ORIGINAL DIAMETER .503 IN. AREA .1987 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 123,805 PSI
TENSILE STRENGTH 164,066 PSI
FINAL DIAMETER .442 IN. FINAL AREA .1534 SQ. IN.
REDUCTION AREA 22.8 %
ELONGATION 12.4 %
Rc 32.9
HF-1 20 BA Long. 1500°F 2hr oil 140°F 1125°F 2hr
45

HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
PRINTED IN U.S.A.



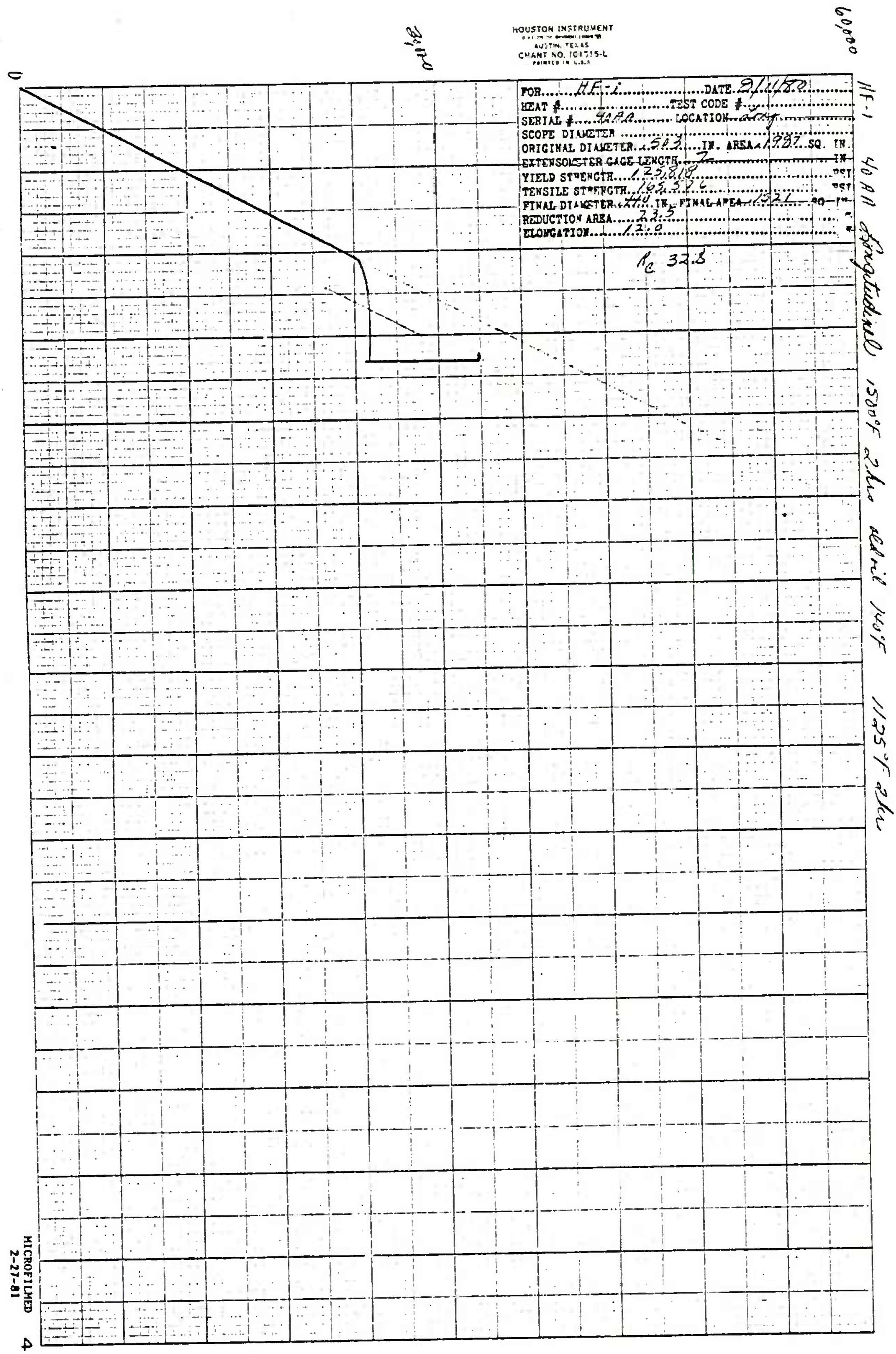
FOR HF-1 DATE 2/12/78
HEAT # TEST CODE #
SERIAL # 20 BD LOCATION [illegible]
SCOPE DIAMETER
ORIGINAL DIAMETER .503 IN. AREA .1987 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 129,785 PSI
TENSILE STRENGTH 168,092 PSI
FINAL DIAMETER .426 IN. FINAL AREA .1425 SQ. IN.
REDUCTION AREA 28.3 %
ELONGATION 12.5% %

Rc 33.9

HF-1 20 BD Longitudinal 1500°F 2hr Air cool 150°F 1125°F 2hrs

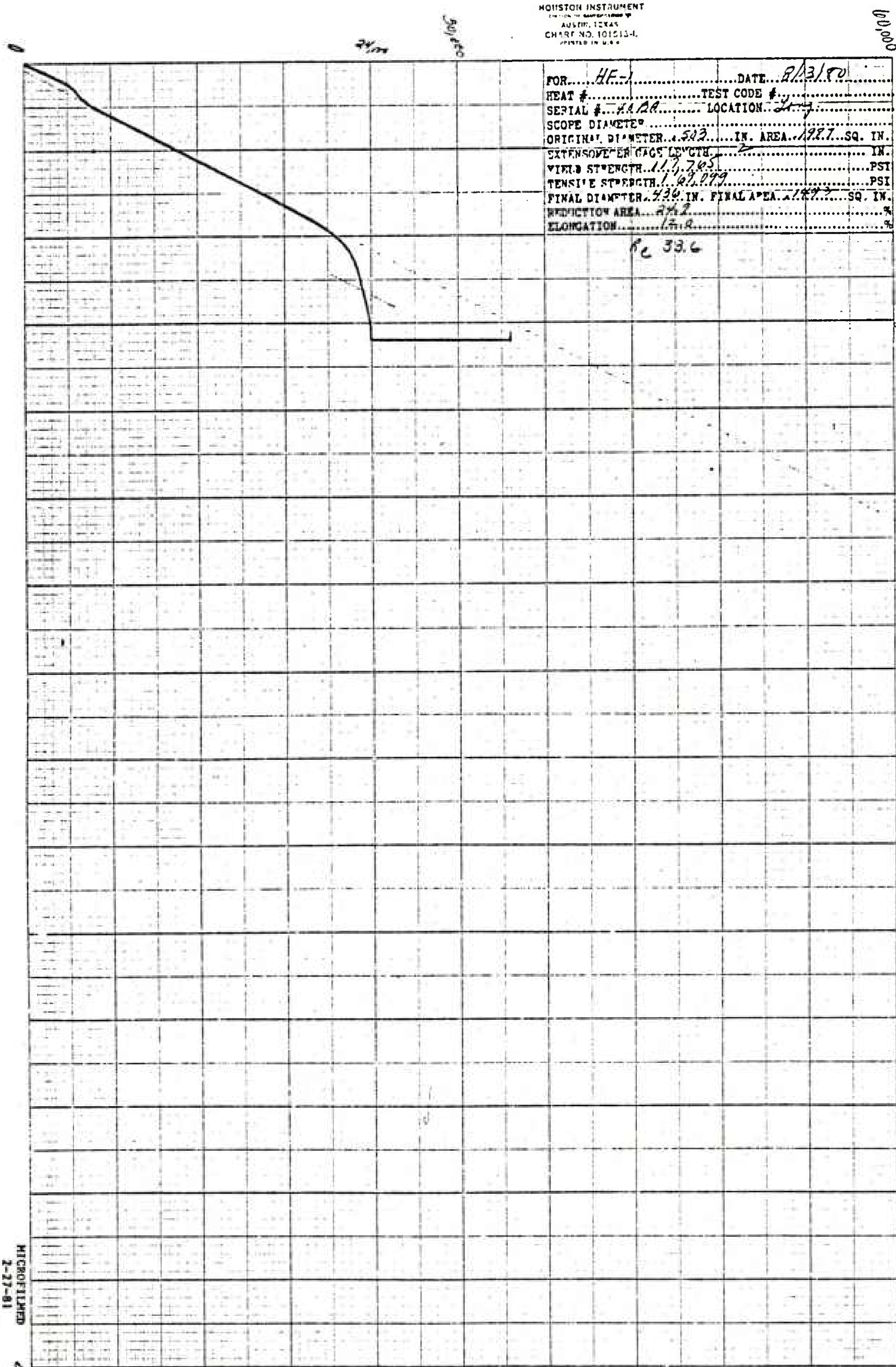
MICROFILMED
2-27-81

46



HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101315-L
PRINTED IN U.S.A.
60,000
34,170
0
FOR HF-1 DATE 2/11/80
HEAT # TEST CODE #
SERIAL # 40AA LOCATION
SCOPE DIAMETER
ORIGINAL DIAMETER .503 IN. AREA .1987 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN
YIELD STRENGTH 125,818 PSI
TENSILE STRENGTH 165,576 PSI
FINAL DIAMETER .440 IN. FINAL AREA .1521 SQ. IN.
REDUCTION AREA 23.5 %
ELONGATION 12.0 %
R_C 32.8
HF-1 40 AA Longitudinal 1500°F 2hr Air 140°F 1125°F 2hr

47



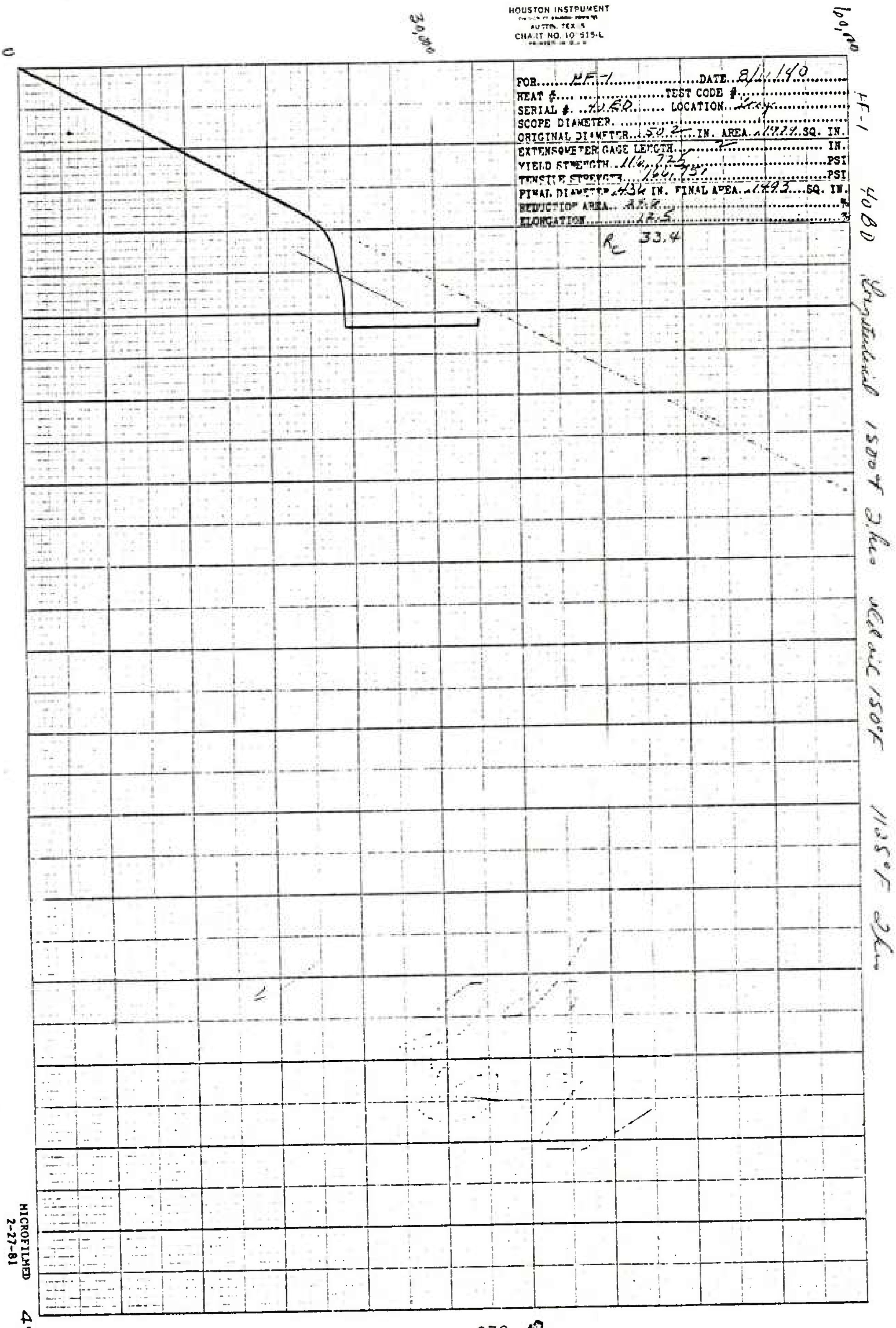
FOR.....HF-1.....DATE 8/13/80
HEAT #.....TEST CODE #.....
SERIAL #...4ABA.....LOCATION...Long
SCOPE DIAMETER.....
ORIGINAL DIAMETER...503.....IN. AREA...1987...SQ. IN.
EXTENSOMETER GAGE LENGTH....2.....IN.
YIELD STRENGTH...117,765.....PSI
TENSILE STRENGTH...169,099.....PSI
FINAL DIAMETER...436...IN. FINAL AREA...1493.....SQ. IN.
REDUCTION AREA....24.2.....%
ELONGATION.....17.0.....%

Rc 33.6

HF-1 40BA Long 1500°F 2hrs oil 1500°F 1125°F 3hrs

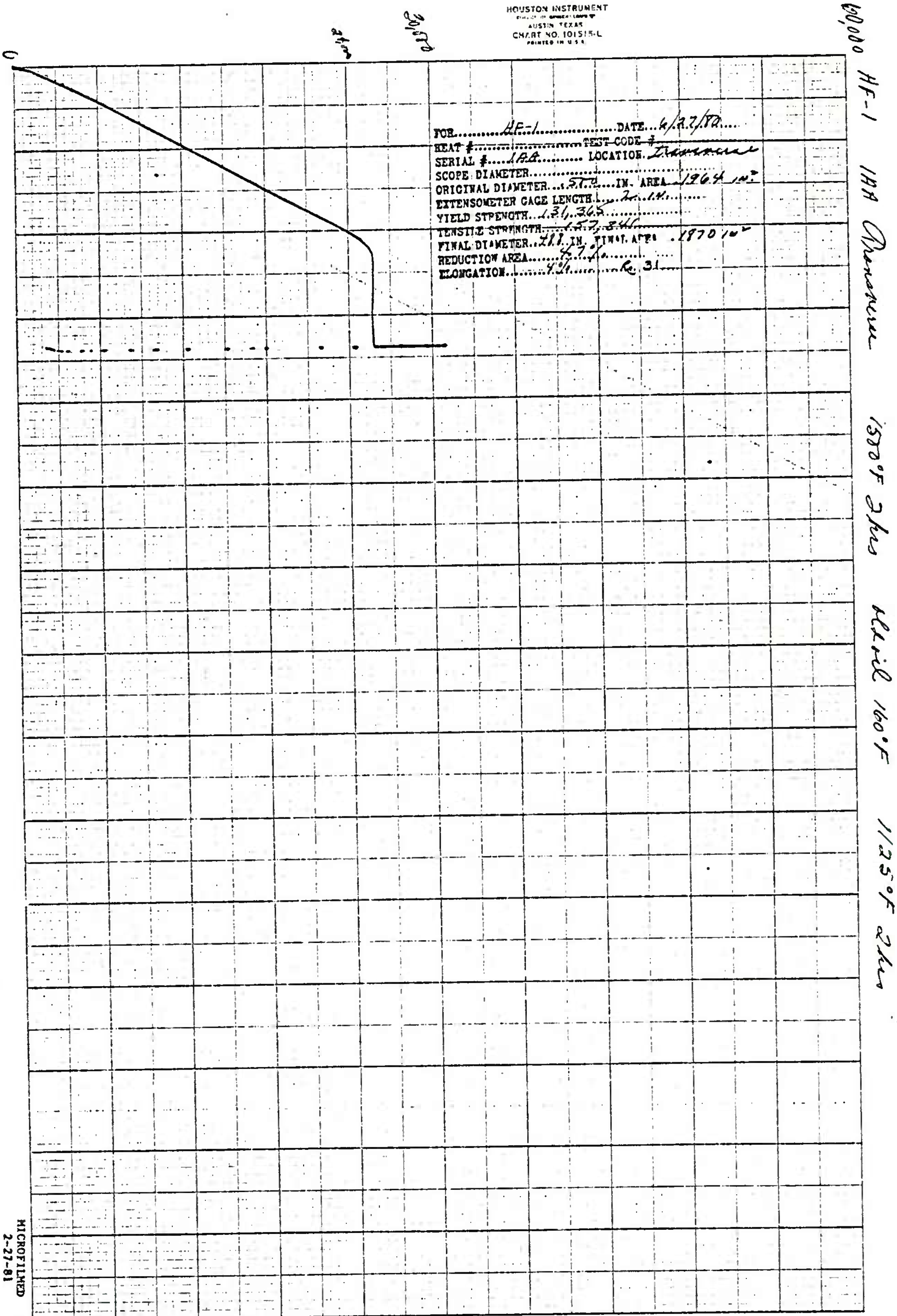
MICROFILMED 2-27-81

48

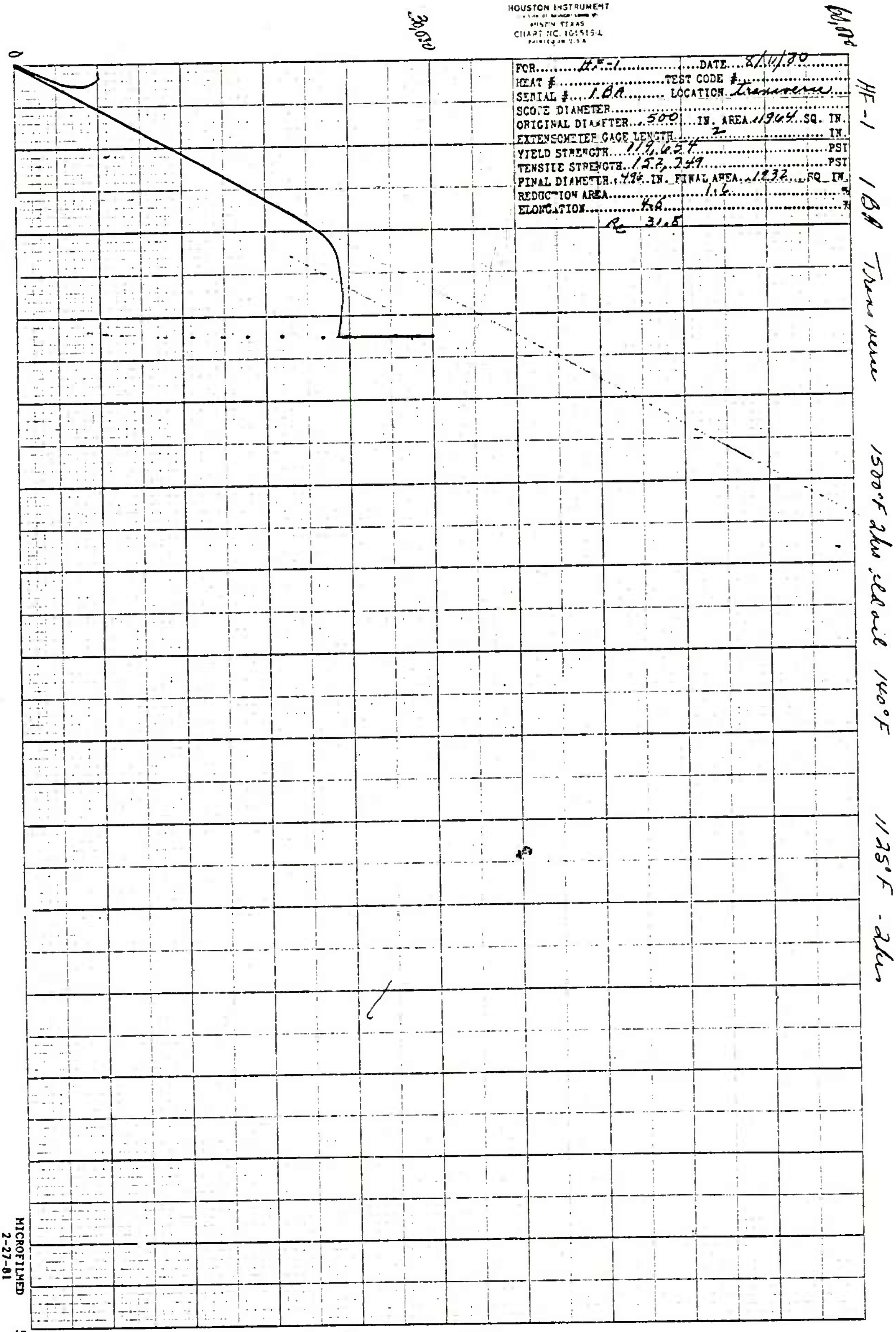


MICROFILMED 2-27-81

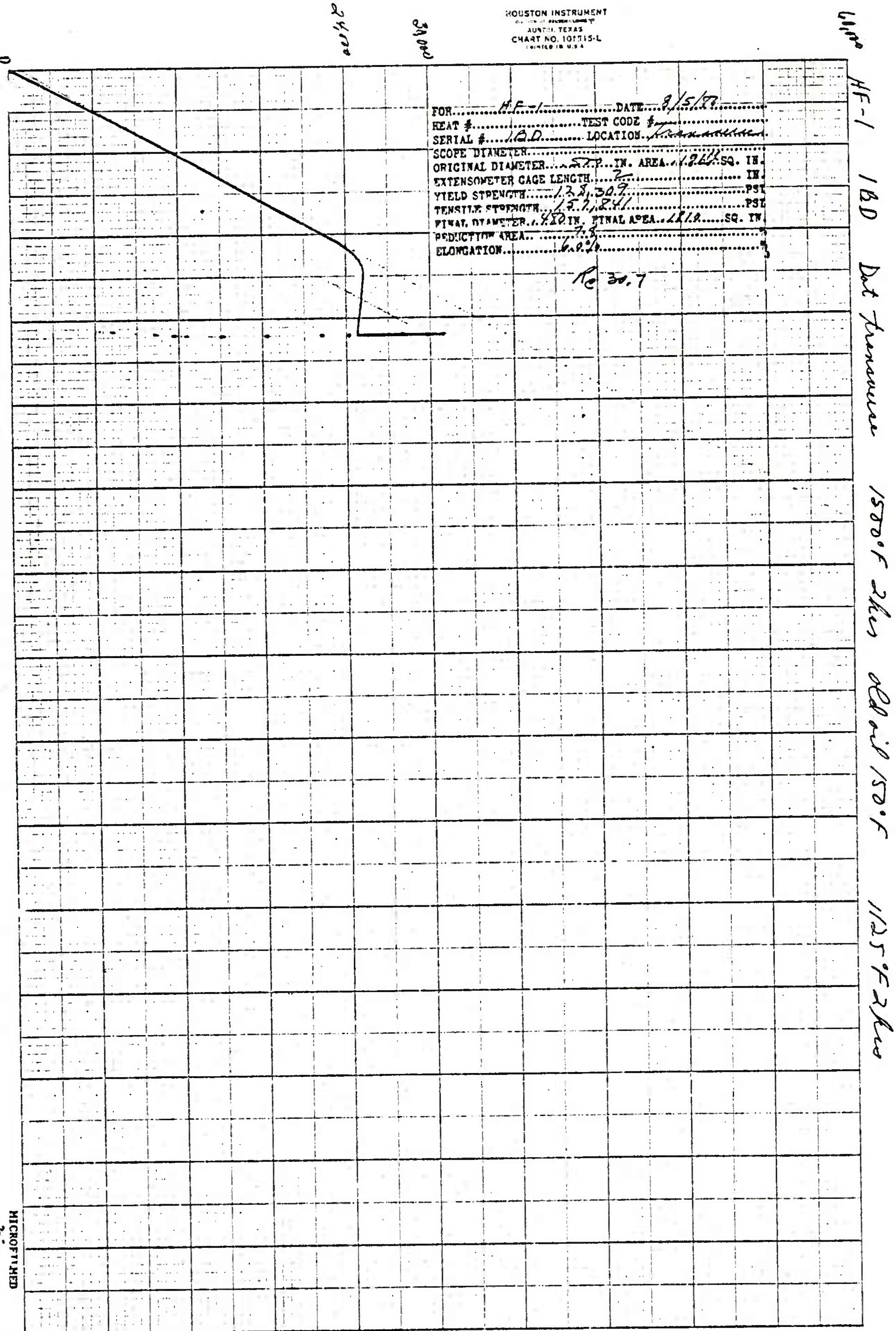
49

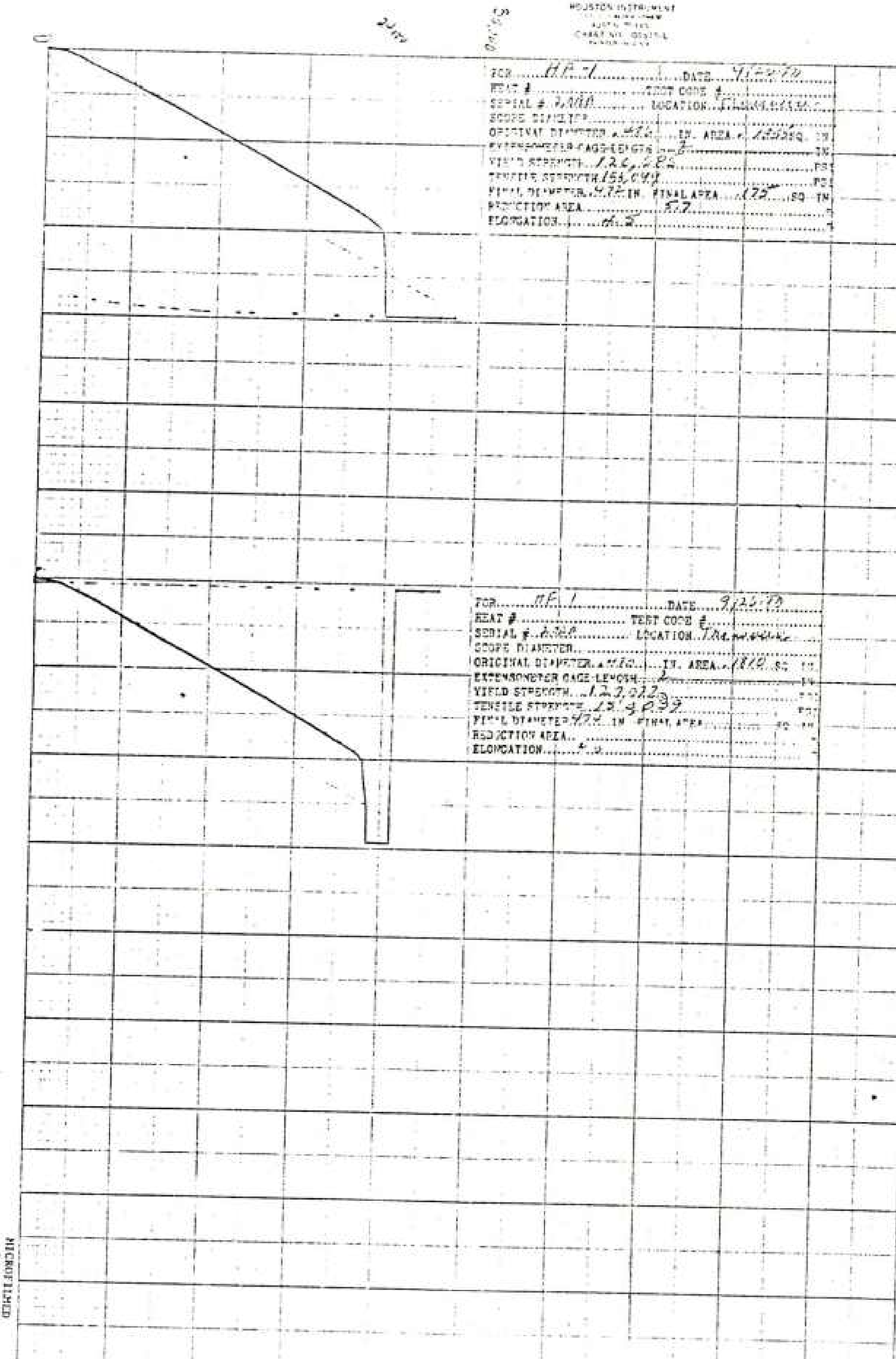


MICROFILMED 2-27-81

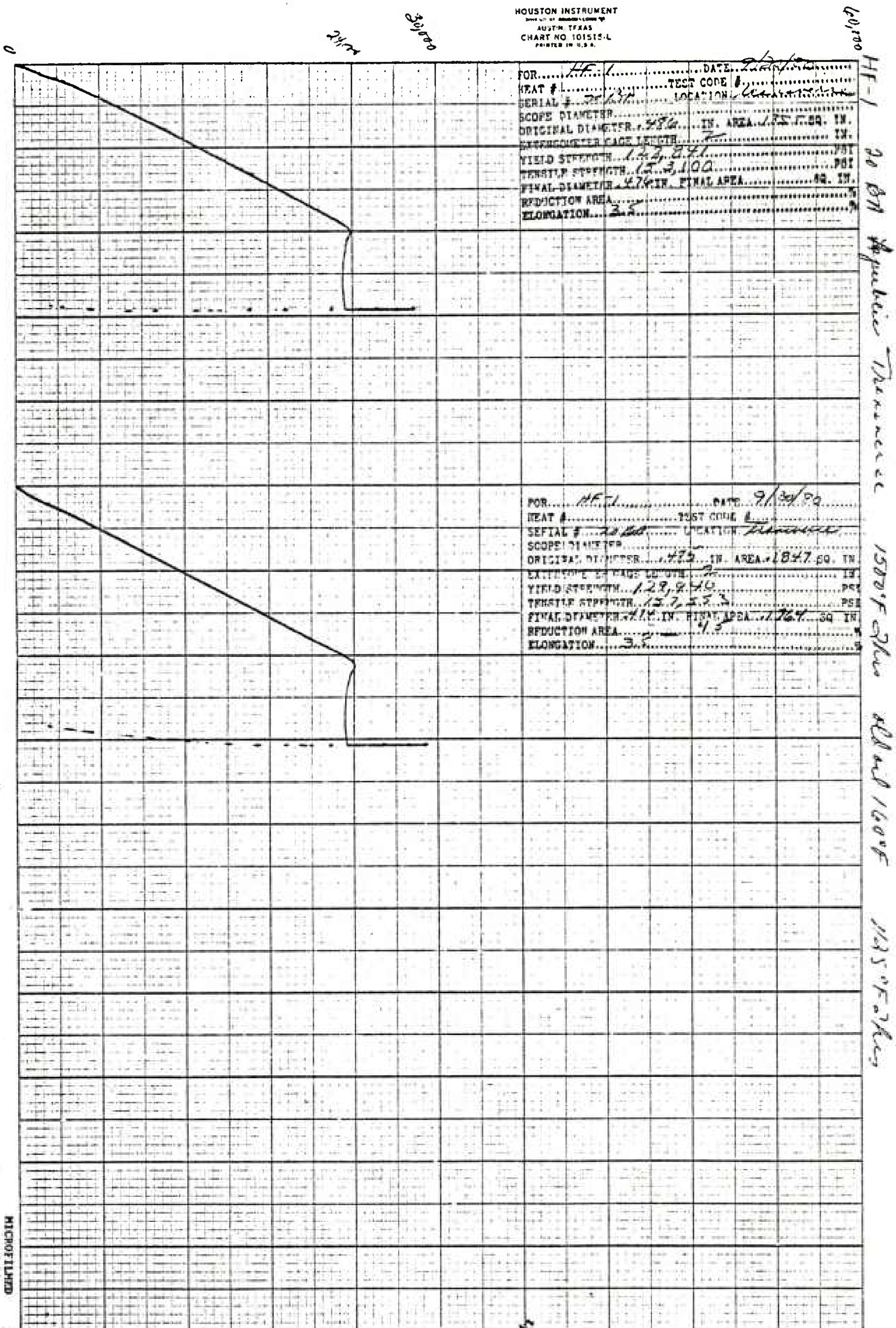

HOUSTON INSTRUMENT
AUSTIN TEXAS
CHART NO. 101515-L
0
30,000
60,000
FOR.....HF-1.....DATE....8/11/80
HEAT #.....TEST CODE #.....
SERIAL #....1.BA.....LOCATION...transverse
SCOPE DIAMETER.....
ORIGINAL DIAMETER....500....IN. AREA..1964...SQ. IN.
EXTENSOMETER GAGE LENGTH.....2.....IN.
YIELD STRENGTH....119,654.....PSI
TENSILE STRENGTH..152,249.....PSI
FINAL DIAMETER..496..IN. FINAL AREA...1232...SQ. IN.
REDUCTION AREA.....1.6.....%
ELONGATION.....4.6.....%
Rc 31.5
HF-1 1BA Transverse 1500°F 2hr oil 140°F 1175°F - 2hr

51


HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101715-L
PRINTED IN U.S.A.
0
24,000
30,000
61,000
FOR HF-1 DATE 8/5/87
HEAT # TEST CODE #
SERIAL # 1BD LOCATION
SCOPE DIAMETER
ORIGINAL DIAMETER .500 IN. AREA .1963 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 128,309 PSI
TENSILE STRENGTH 157,841 PSI
FINAL DIAMETER .480 IN. FINAL AREA .1810 SQ. IN.
REDUCTION AREA 7.8
ELONGATION 6.0%
Rc 30.7
HF-1 1BD Dot Furnace 1500°F 2hrs Cl oil 150°F 1125°F 2hrs

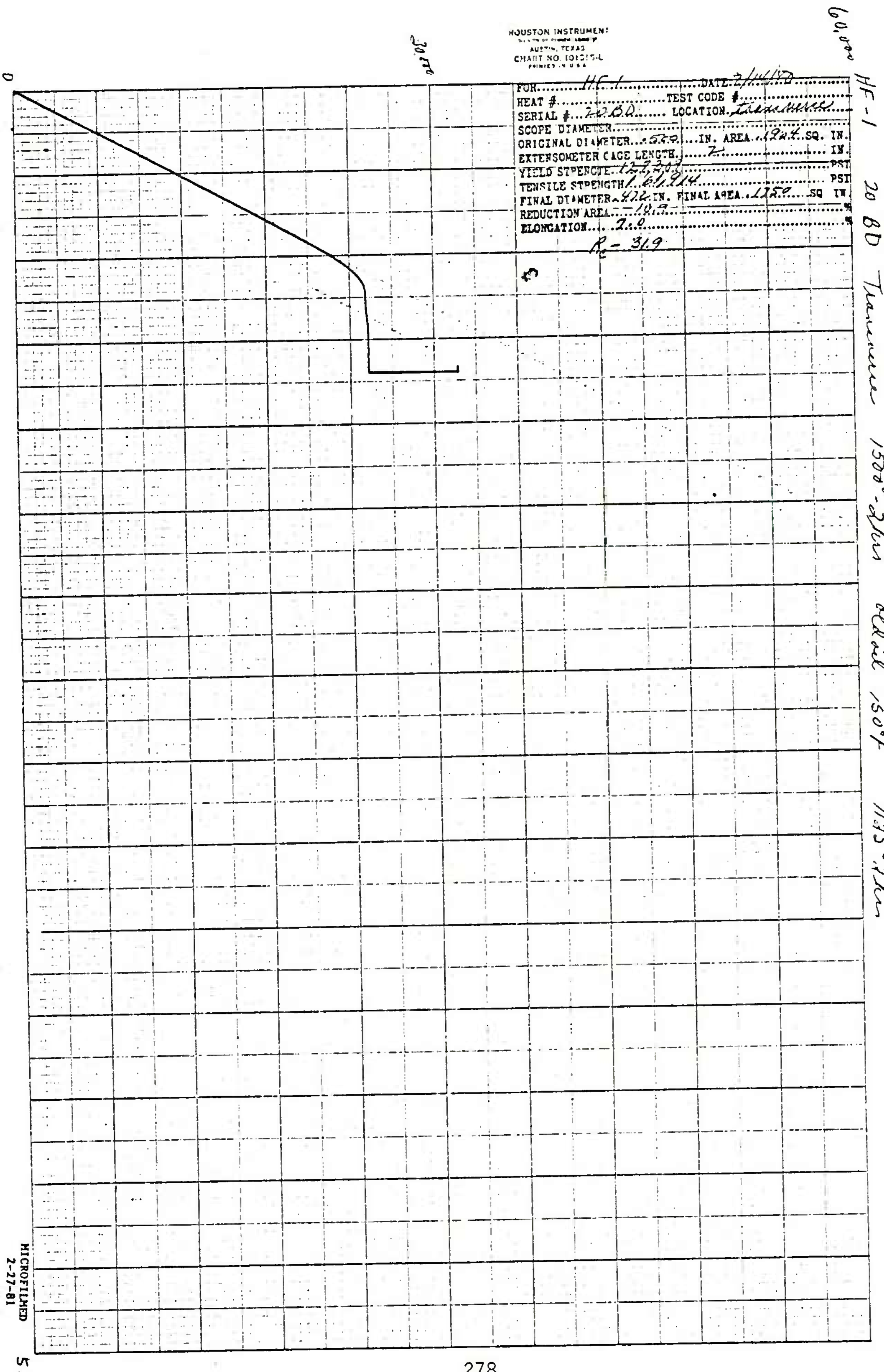

HOUSTON INSTRUMENT
FOR HP-1 DATE 9/25/79
HEAT #
TEST CODE #
SERIAL # 2000
LOCATION
SCOPE DIAMETER
ORIGINAL DIAMETER
IN. AREA
SQ. IN
EXTENSOMETER GAGE LENGTH 2
IN
YIELD STRENGTH 126,282
PSI
TENSILE STRENGTH 154,049
PSI
FINAL DIAMETER .472 IN. FINAL AREA .175 SQ. IN
REDUCTION AREA 57
ELONGATION
FOR HP-1 DATE 9/25/79
HEAT #
TEST CODE #
SERIAL #
LOCATION
SCOPE DIAMETER
ORIGINAL DIAMETER
IN. AREA .1810 SQ. IN
EXTENSOMETER GAGE LENGTH 2
IN
YIELD STRENGTH 127,072
PSI
TENSILE STRENGTH
PSI
FINAL DIAMETER
IN FINAL AREA
SQ. IN
REDUCTION AREA
ELONGATION

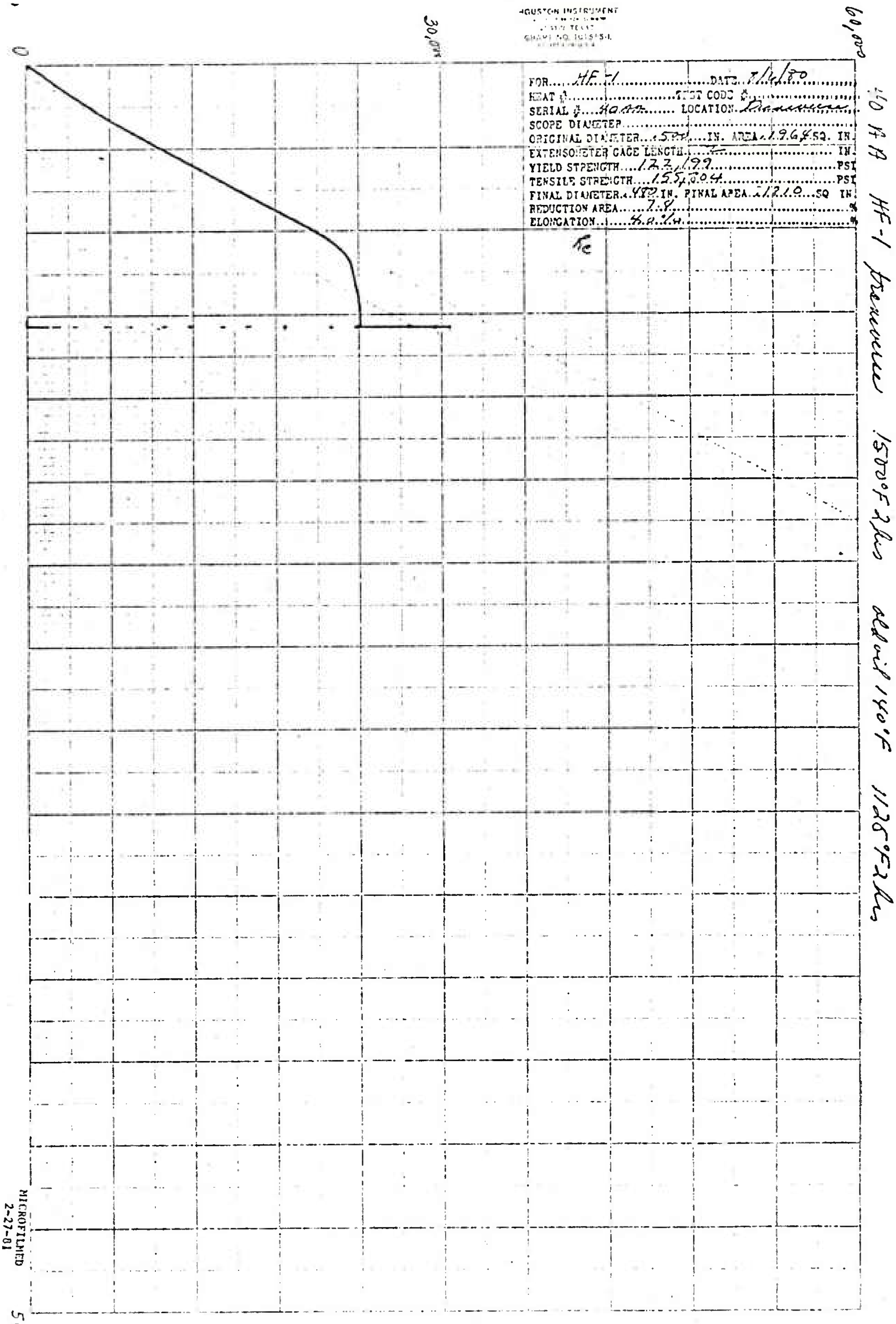
1500°F

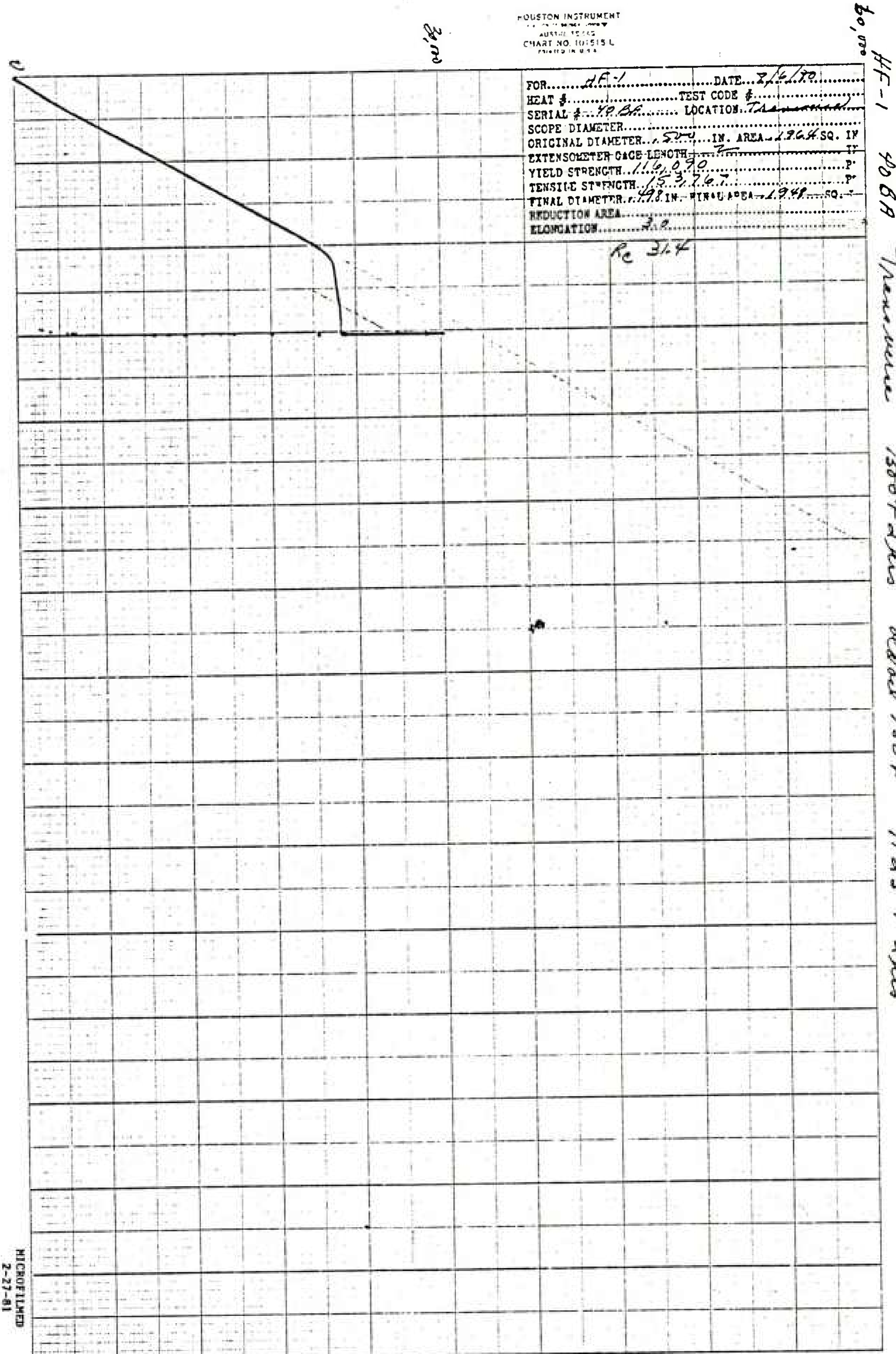


MICROFILMED 2-27-81

54

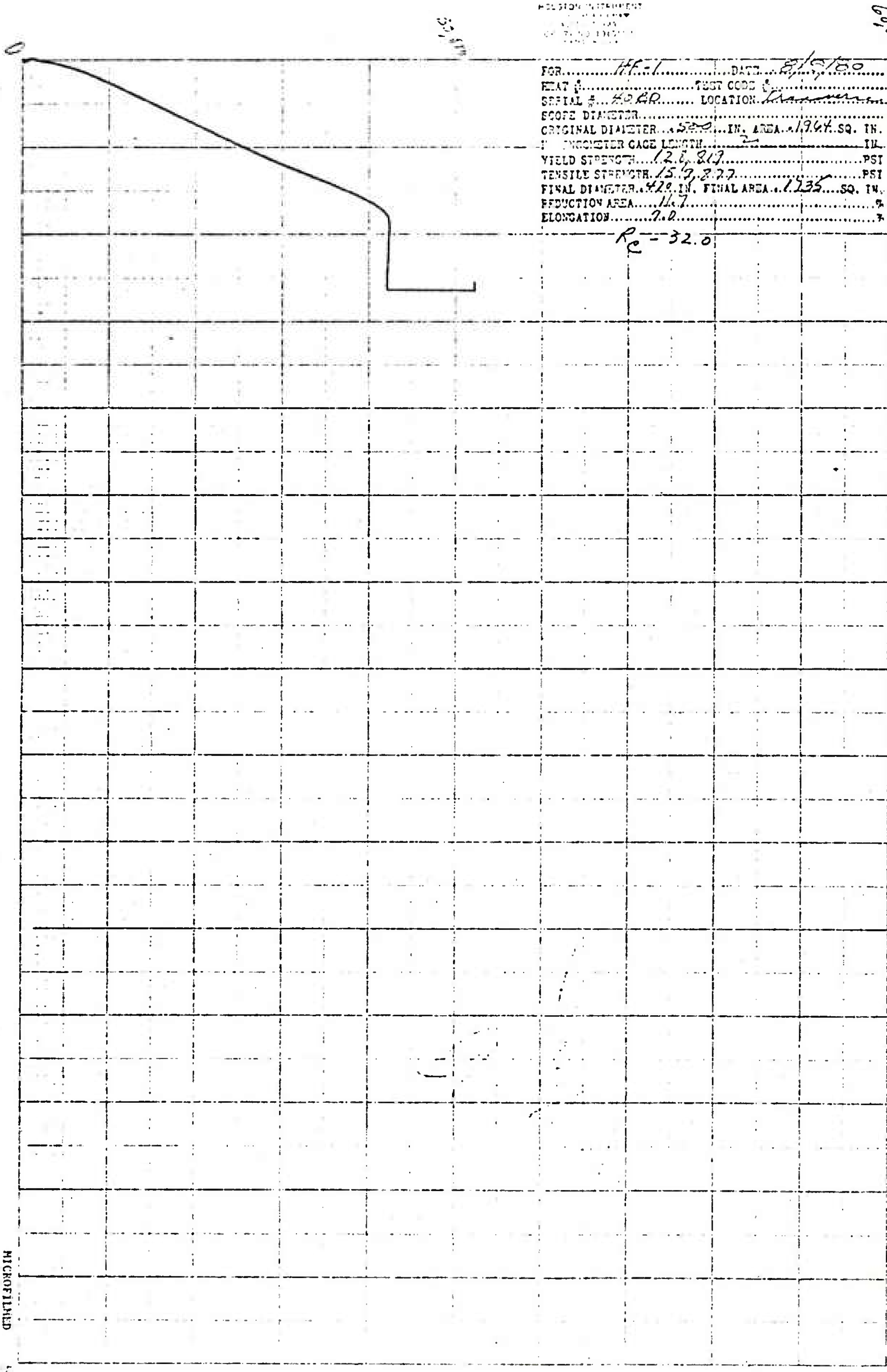

HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
PRINTED IN U.S.A.
0
30,000
60,000
FOR....HF-1....DATE 2/14/80
HEAT #....TEST CODE #....
SERIAL #...20BD..... LOCATION. transverse
SCOPE DIAMETER....
ORIGINAL DIAMETER....500....IN. AREA ..1924..SQ. IN.
EXTENSOMETER GAGE LENGTH.....2.....IN.
YIELD STRENGTH..122,203....PSI
TENSILE STRENGTH 161,914....PSI
FINAL DIAMETER .472 IN. FINAL AREA ..1750....SQ IN.
REDUCTION AREA...10.9....%
ELONGATION....2.0....%
R_c - 31.9
HF-1 20 BD Transverse 1500°-2hr Oil 150°F 1125°-2hr
55


HOUSTON INSTRUMENT
CHART NO. 1015PS-L
0
30,000
60,000
FOR HF-1 DATE 7/4/80
HEAT #
TEST CODE #
SERIAL # 40 ...
LOCATION
SCOPE DIAMETER
ORIGINAL DIAMETER .500 IN. AREA .1964 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 122,199 PSI
TENSILE STRENGTH 155,804 PSI
FINAL DIAMETER .480 IN. FINAL AREA .1810 SQ IN.
REDUCTION AREA 7.8 %
ELONGATION 6.0 % %
40 HA HF-1 ... 1500°F 2hr ... 1400°F 1125°F 2hr
MICROFILMED 2-27-81
56

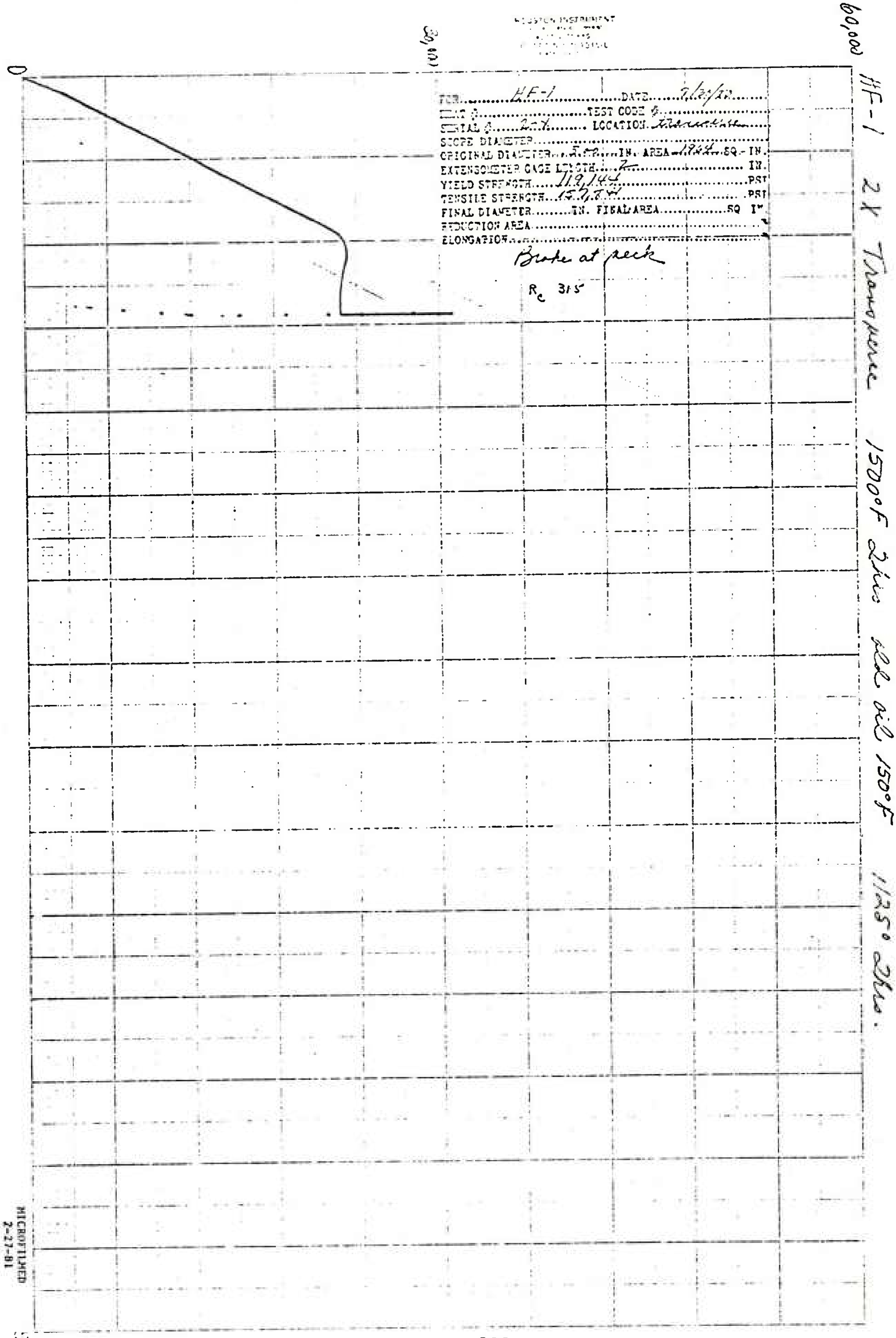


HOUSTON INSTRUMENT
CHART NO. 107515 L
20,000
60,000 HF-1 40BA Transverse
FOR HF-1 DATE 2/6/80
HEAT #
TEST CODE #
SERIAL # 40BA LOCATION Transverse
SCOPE DIAMETER
ORIGINAL DIAMETER .500 IN. AREA .1964 SQ. IN
EXTENSOMETER GAGE LENGTH 2
YIELD STRENGTH 116,090
TENSILE STRENGTH 153,767
FINAL DIAMETER .498 IN. FINAL AREA .1948 SQ.
REDUCTION AREA
ELONGATION 3.0
Rc 31.4
1800°F 2 hrs Oil 150°F 1125°F 2 hrs

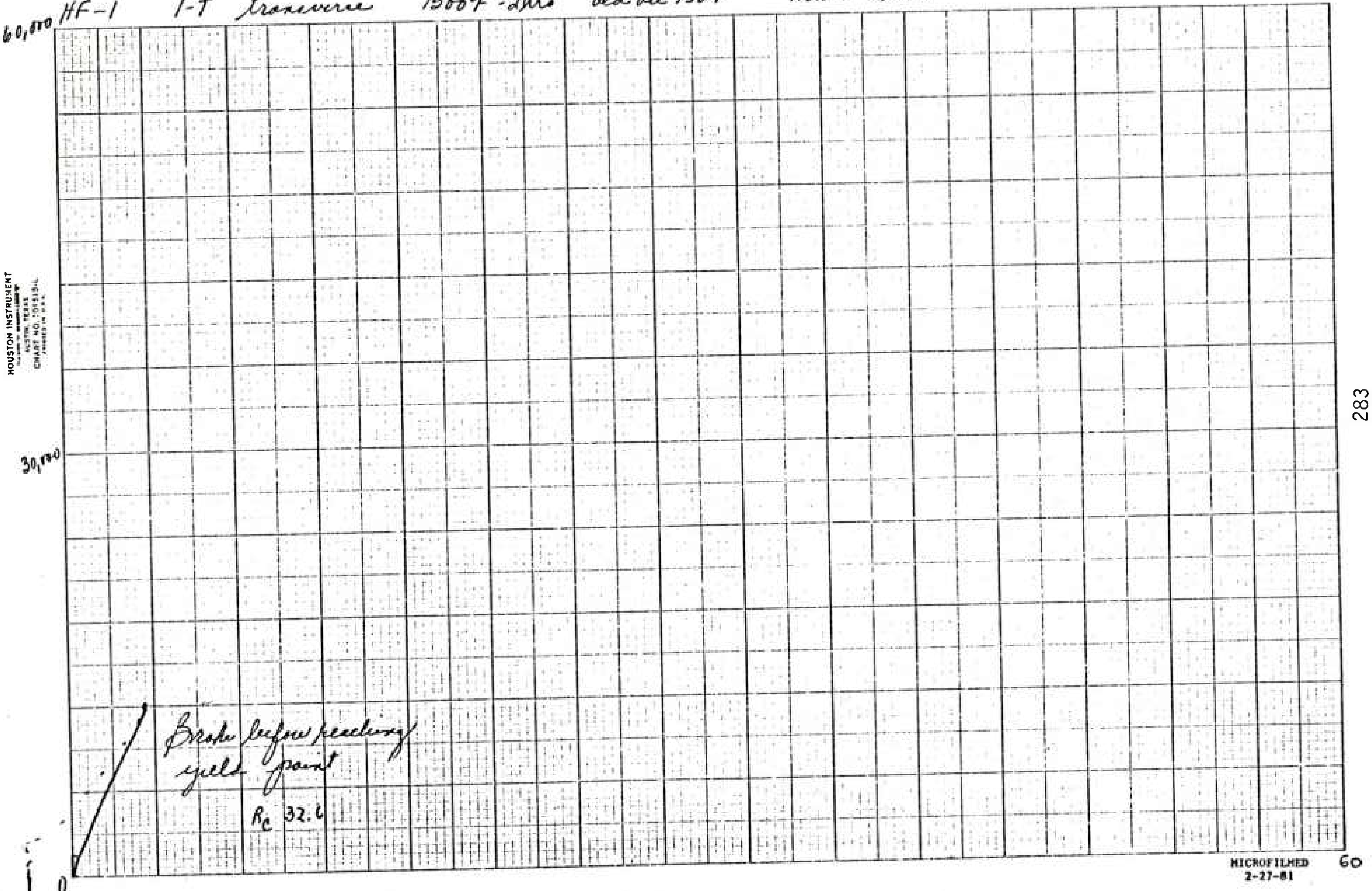
57

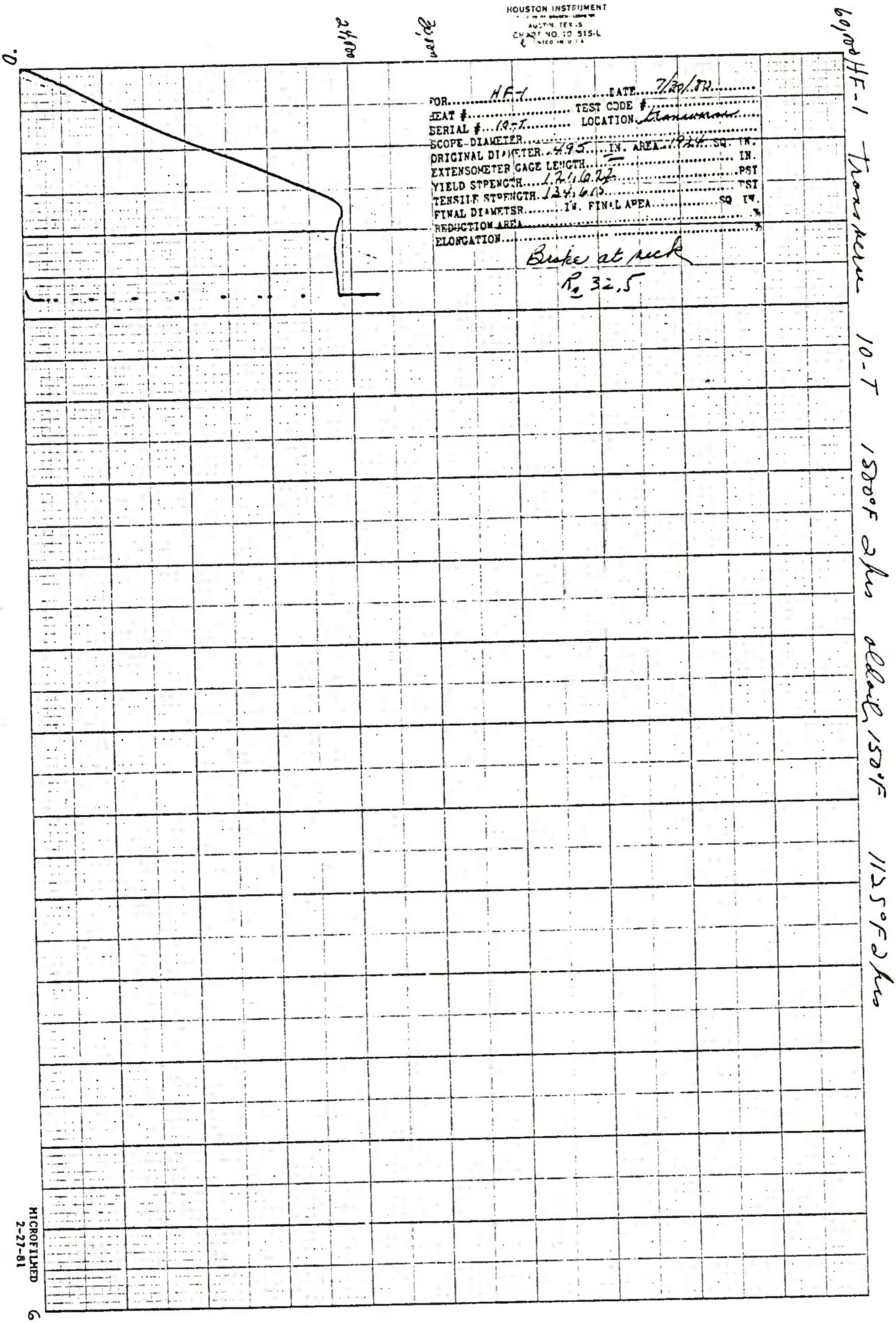


HF-1 40BD Transverse 1500°F 2hrs oil 150°F 1150 2hrs

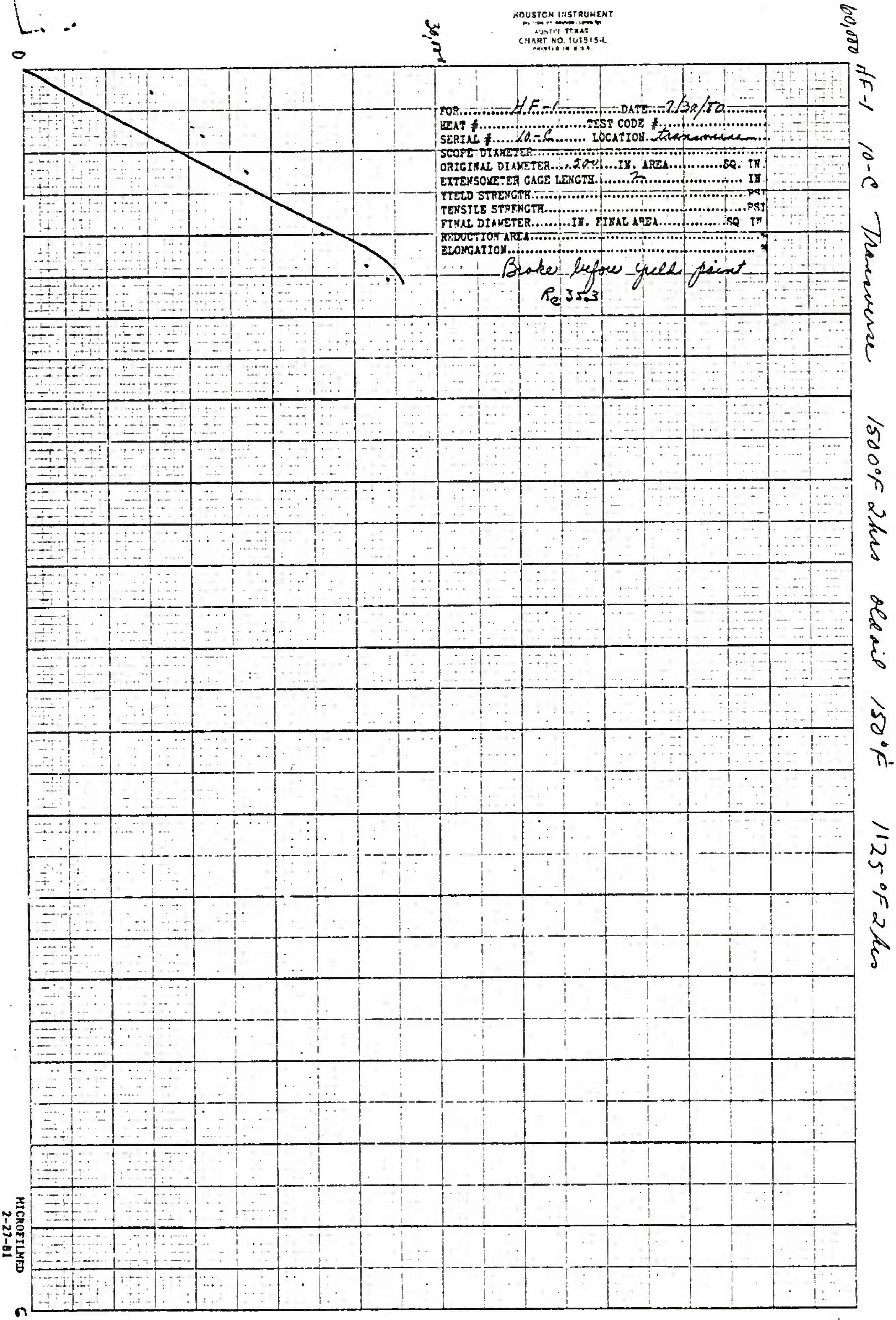

0
30,000
60,000
FOR HF-1 DATE 7/23/80
HEAT # TEST CODE #
SERIAL # 2-X LOCATION transverse
SCOPE DIAMETER
ORIGINAL DIAMETER .500 IN. AREA .1964 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 119,144 PSI
TENSILE STRENGTH 157,844 PSI
FINAL DIAMETER IN. FINAL AREA SQ IN.
REDUCTION AREA
ELONGATION
Broke at neck
Rc 31.5
HF-1 2X Transverse 1500°F 2hrs old oil 150°F 1125° 2hrs.
MICROFILMED 2-27-81
50

HF-1 1-T transverse 1500°F-2hrs old oil 150°F 1125°F 2hrs



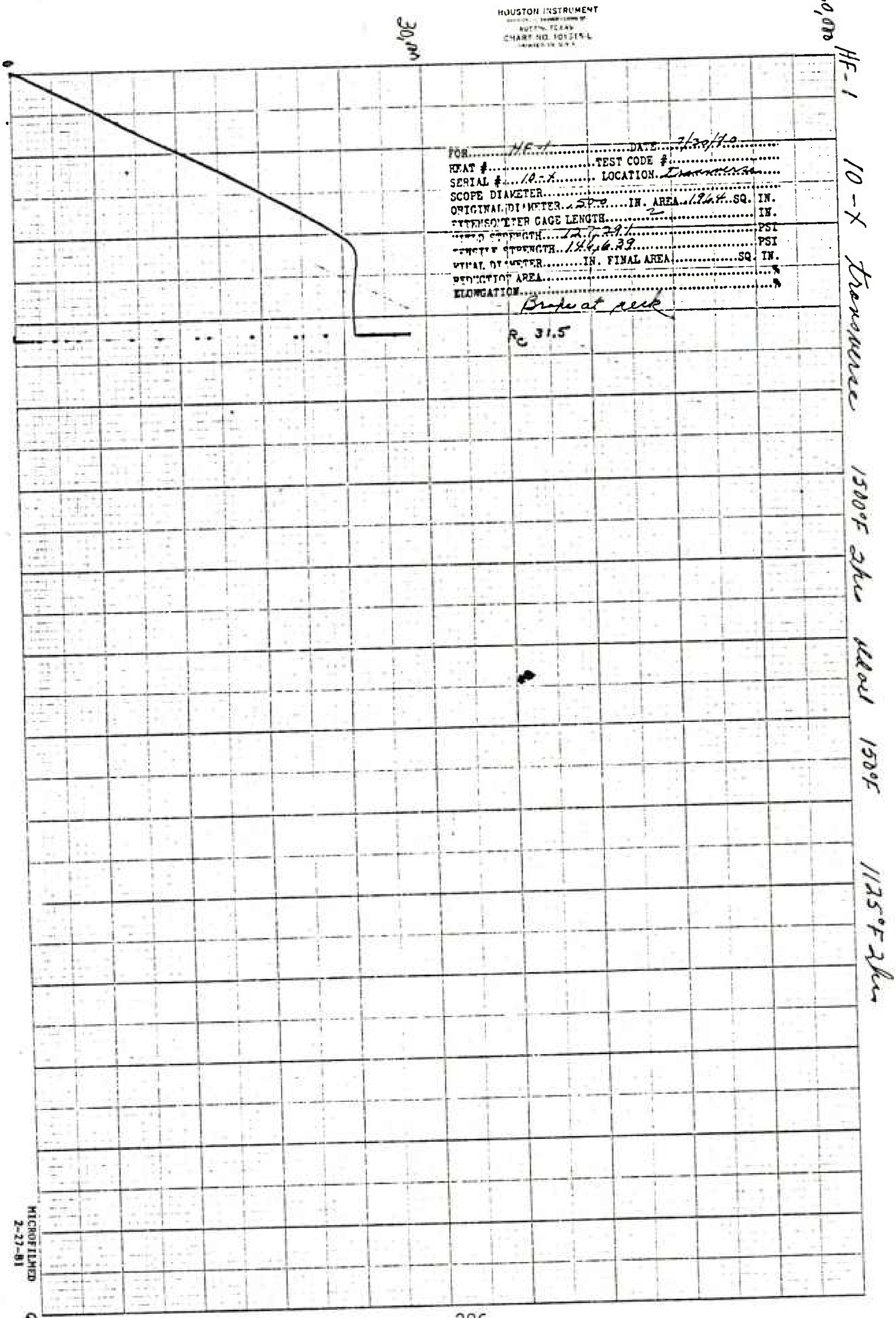

HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 10 515-L
0.
60,000
FOR HF-1 DATE 7/30/80
HEAT # TEST CODE #
SERIAL # 10-T LOCATION Transverse
SCOPE-DIAMETER
ORIGINAL DIAMETER .495 IN. AREA .1924 SQ. IN.
EXTENSOMETER GAGE LENGTH IN.
YIELD STRENGTH 124,622 PSI
TENSILE STRENGTH 134,615 PSI
FINAL DIAMETER IN. FINAL AREA SQ IN.
REDUCTION AREA %
ELONGATION %
Broke at neck
Rc 32.5
HF-1 Transverse 10-T 1500°F 2hrs
1125°F 2hrs
MICROFILMED 2-27-81
61

HOUSTON INSTRUMENT
AUSTIN TEXAS
CHART NO. 101515-L
PRINTED IN U.S.A.

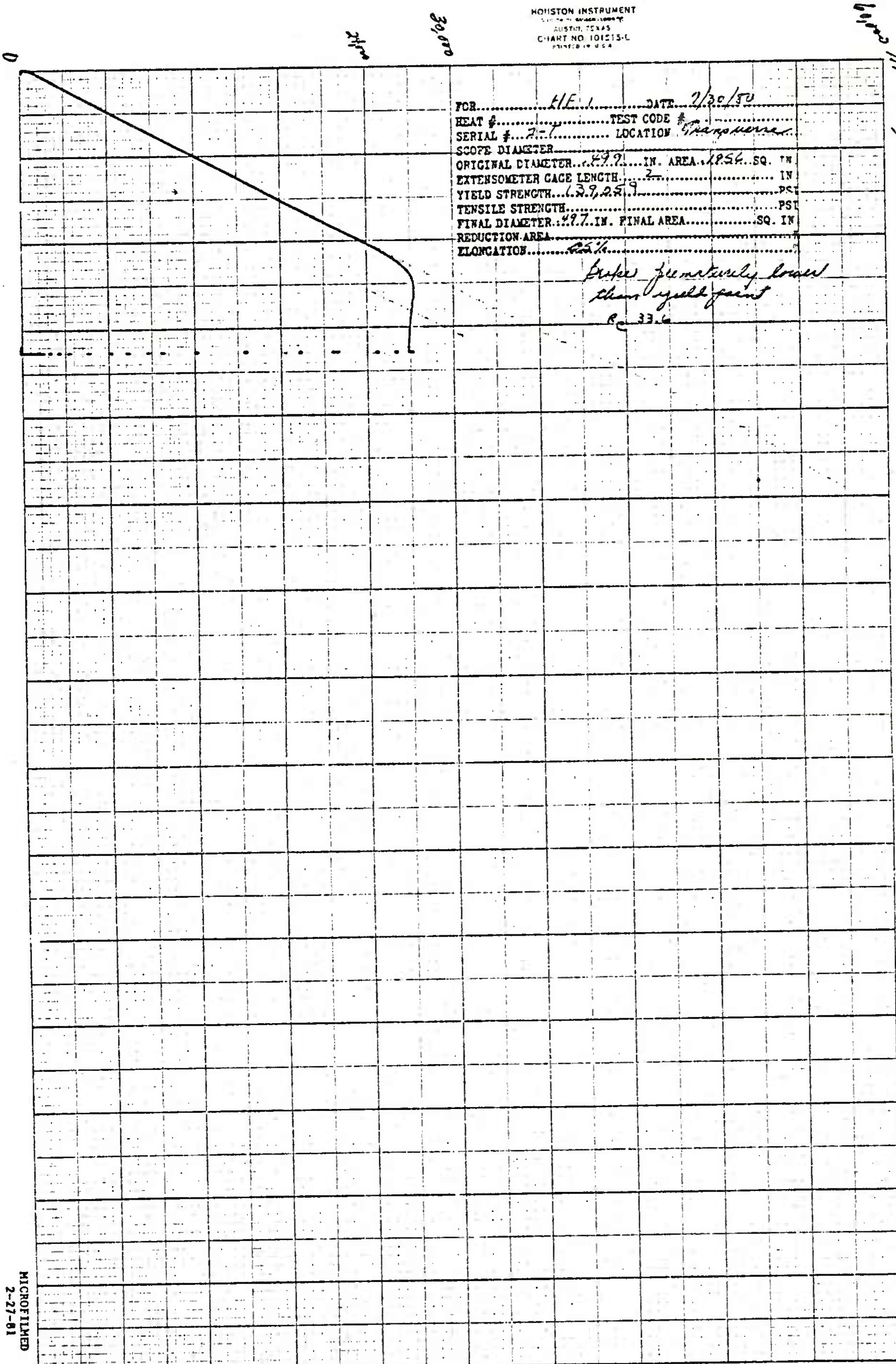


MICROFILMED 2-27-81

C2

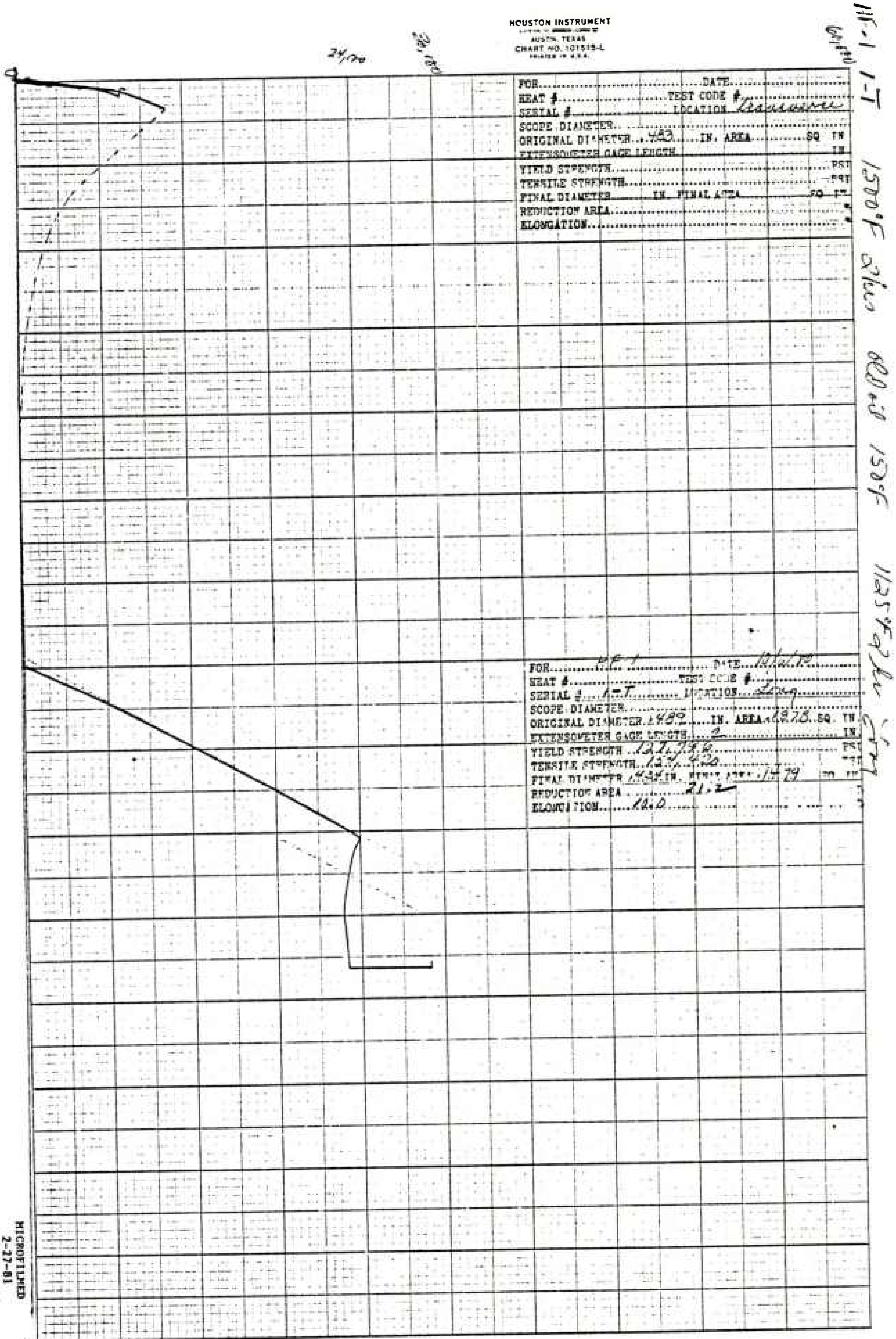

HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101315-L
30,000
60,000
HF-1 10-X Transverse 1500°F 2hr Cool 150°F 1125°F 2hr
FOR HF-1 DATE 7/30/70
HEAT #
TEST CODE #
SERIAL # 10-X
LOCATION Transverse
SCOPE DIAMETER
ORIGINAL DIAMETER .500 IN. AREA .1964 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 127,291 PSI
TENSILE STRENGTH 144,639 PSI
FINAL DIAMETER IN. FINAL AREA SQ. IN.
REDUCTION AREA %
ELONGATION %
Broke at neck
R_C 31.5
MICROFILMED 2-27-81

G 3



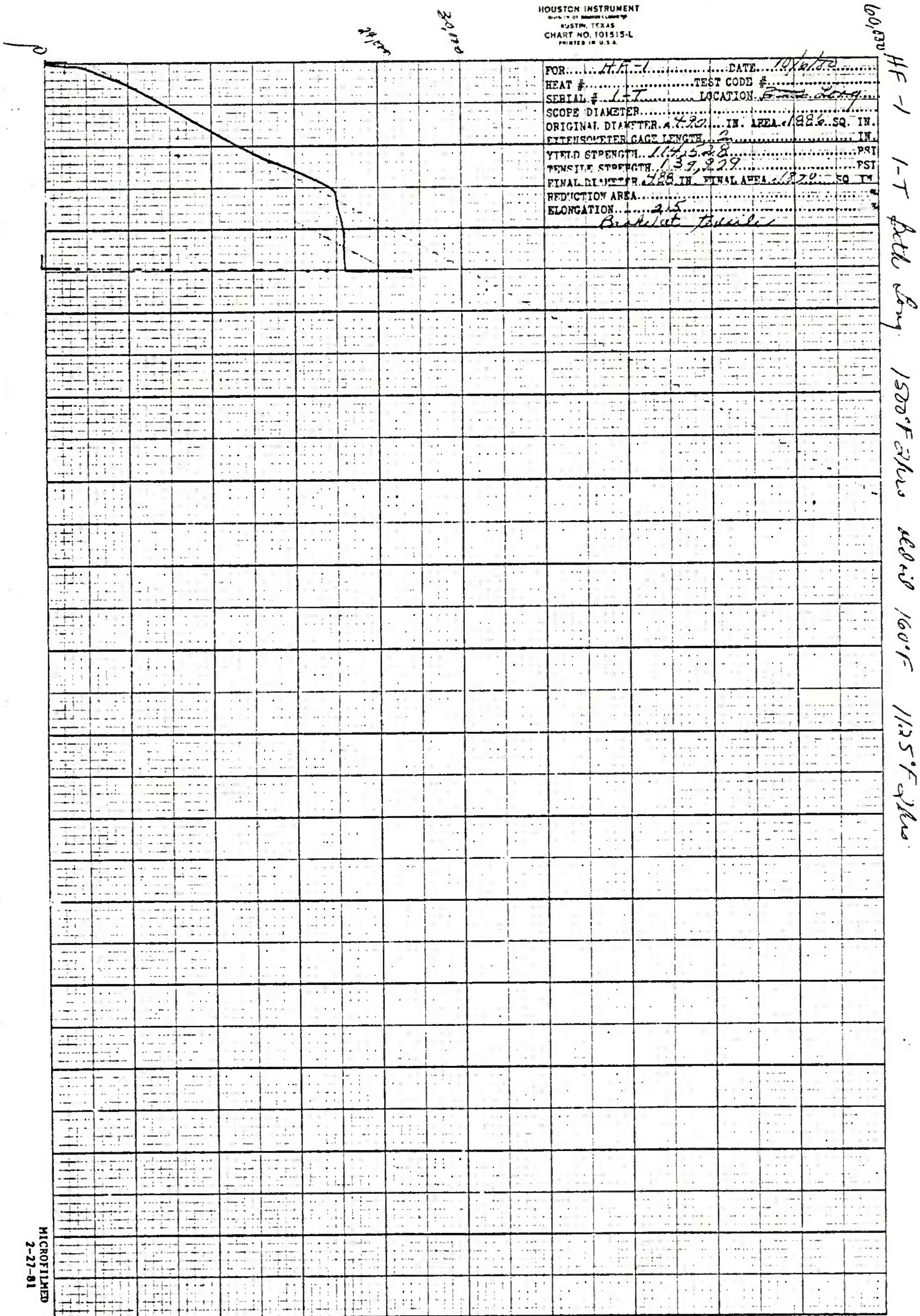
HF-1 Transverse 2-T 1500°F 1hr oil 150°F 1125°F 2hrs

64

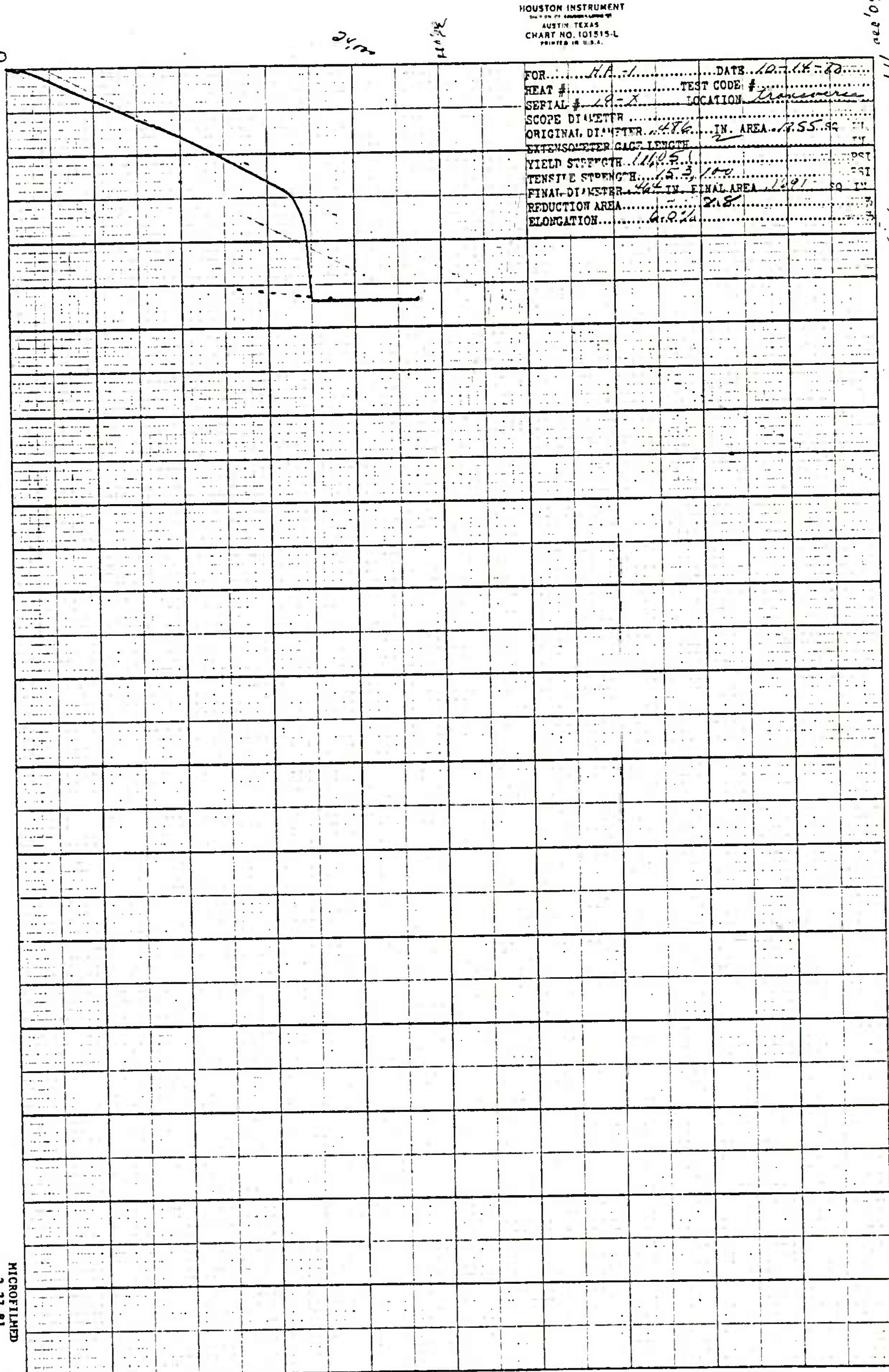


MICROFILMED
2-27-81

65



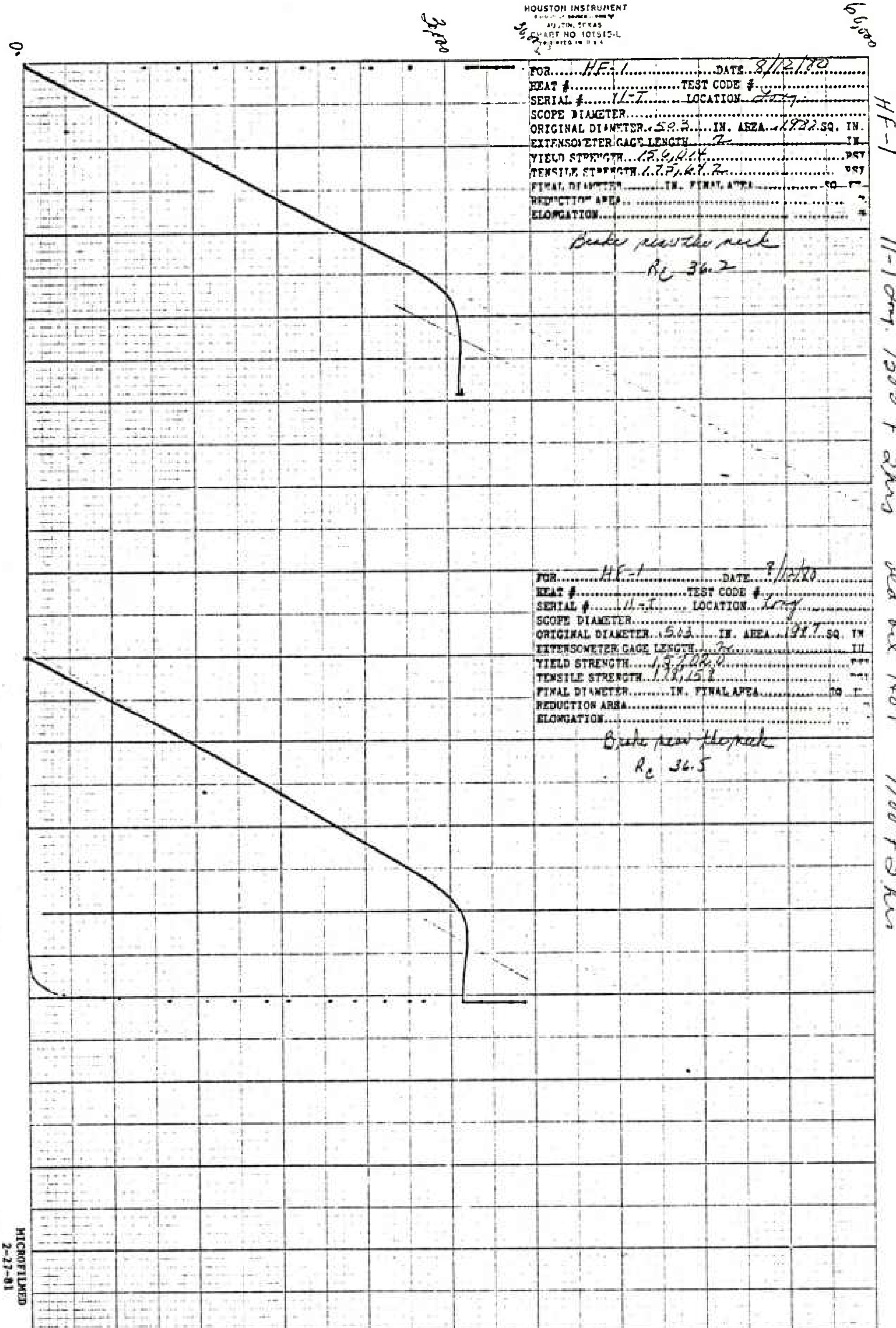
MICROFILMED 2-27-81 G6



60,000 HF-1 19-X transverse

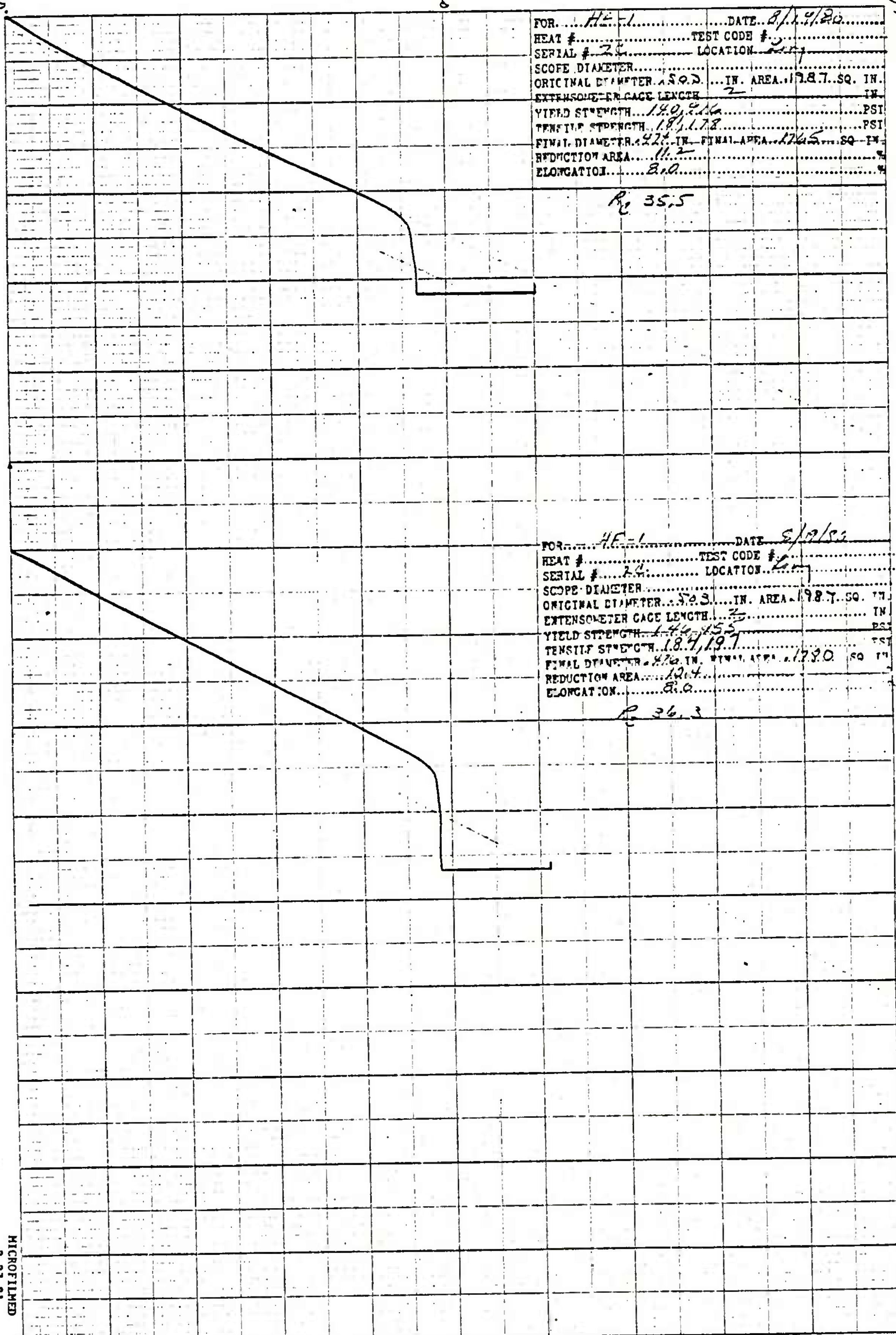
MICROFILMED 2-27-81

67


HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO 101513-L
0.
3,700
66,000
FOR HF-1 DATE 8/12/80
HEAT #
TEST CODE #
SERIAL # 11-T
LOCATION Long
SCOPE DIAMETER
ORIGINAL DIAMETER .503 IN. AREA .1987 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 159,014 PSI
TENSILE STRENGTH 177,642 PSI
FINAL DIAMETER IN. FINAL AREA SQ. IN.
REDUCTION AREA %
ELONGATION %
Broke near the neck
Rc 36.2
HF-1
11-T Long. 1500°F 2 hrs old oil 140°F 1100°F 2 hrs
FOR HF-1 DATE 8/12/80
HEAT #
TEST CODE #
SERIAL # 11-T
LOCATION Long
SCOPE DIAMETER
ORIGINAL DIAMETER .503 IN. AREA .1987 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 157,020 PSI
TENSILE STRENGTH 178,152 PSI
FINAL DIAMETER IN. FINAL AREA SQ. IN.
REDUCTION AREA
ELONGATION
Broke near the neck
Rc 36.5

89

HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101-15-L



HF-1 2-2C 1550°F 2hrs oil 150°F 1025°F 2hrs Long.

FOR. HE-1 DATE 8/29/80
HEAT #. TEST CODE # 2
SERIAL # 22 LOCATION Long
SCOPE DIAMETER.
ORIGINAL DIAMETER .503 IN. AREA .1987 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 140,216 PSI
TENSILE STRENGTH 181,178 PSI
FINAL DIAMETER .475 IN. FINAL AREA .1765 SQ. IN.
REDUCTION AREA 11.2 %
ELONGATION 8.0 %

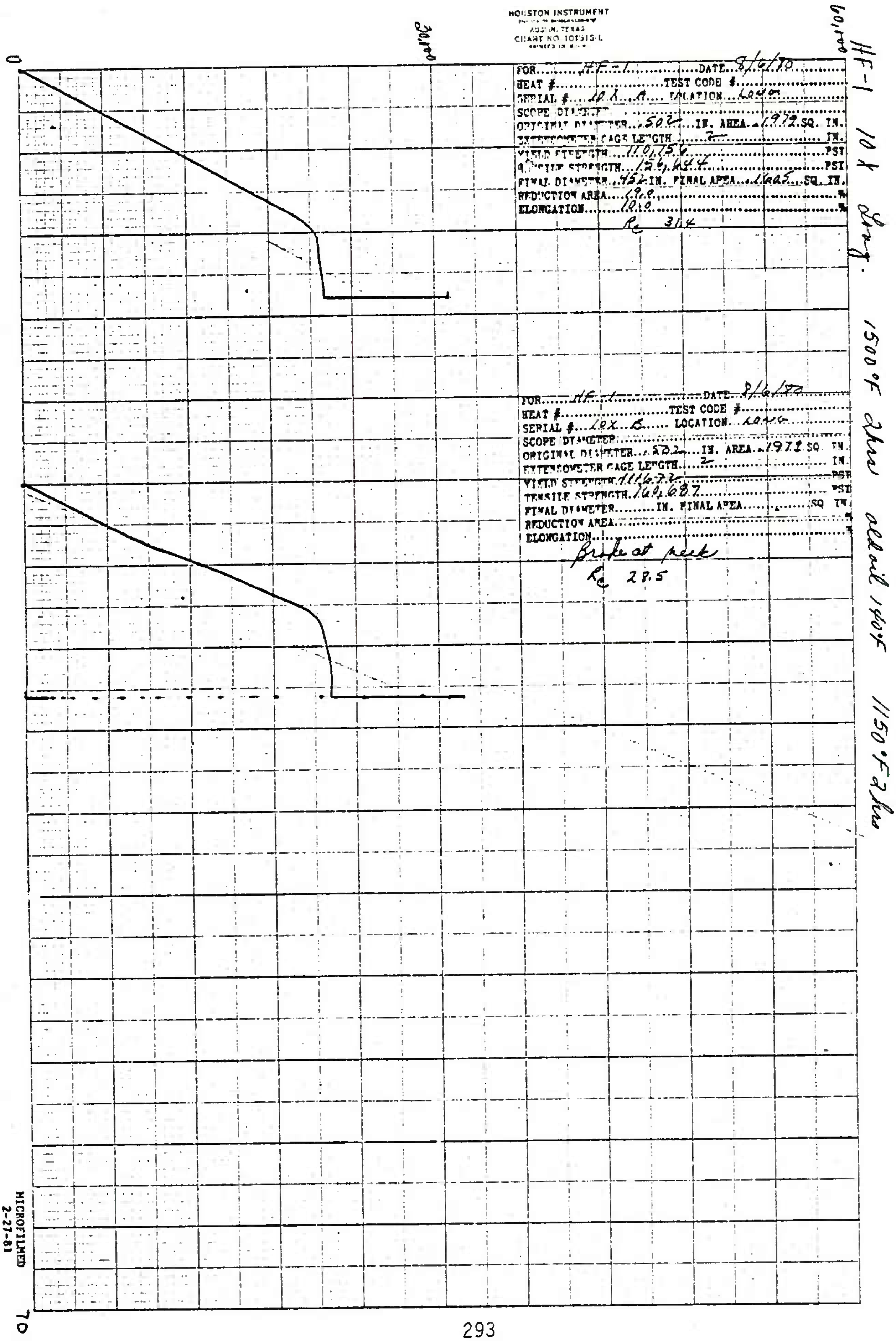
R_c 35.5

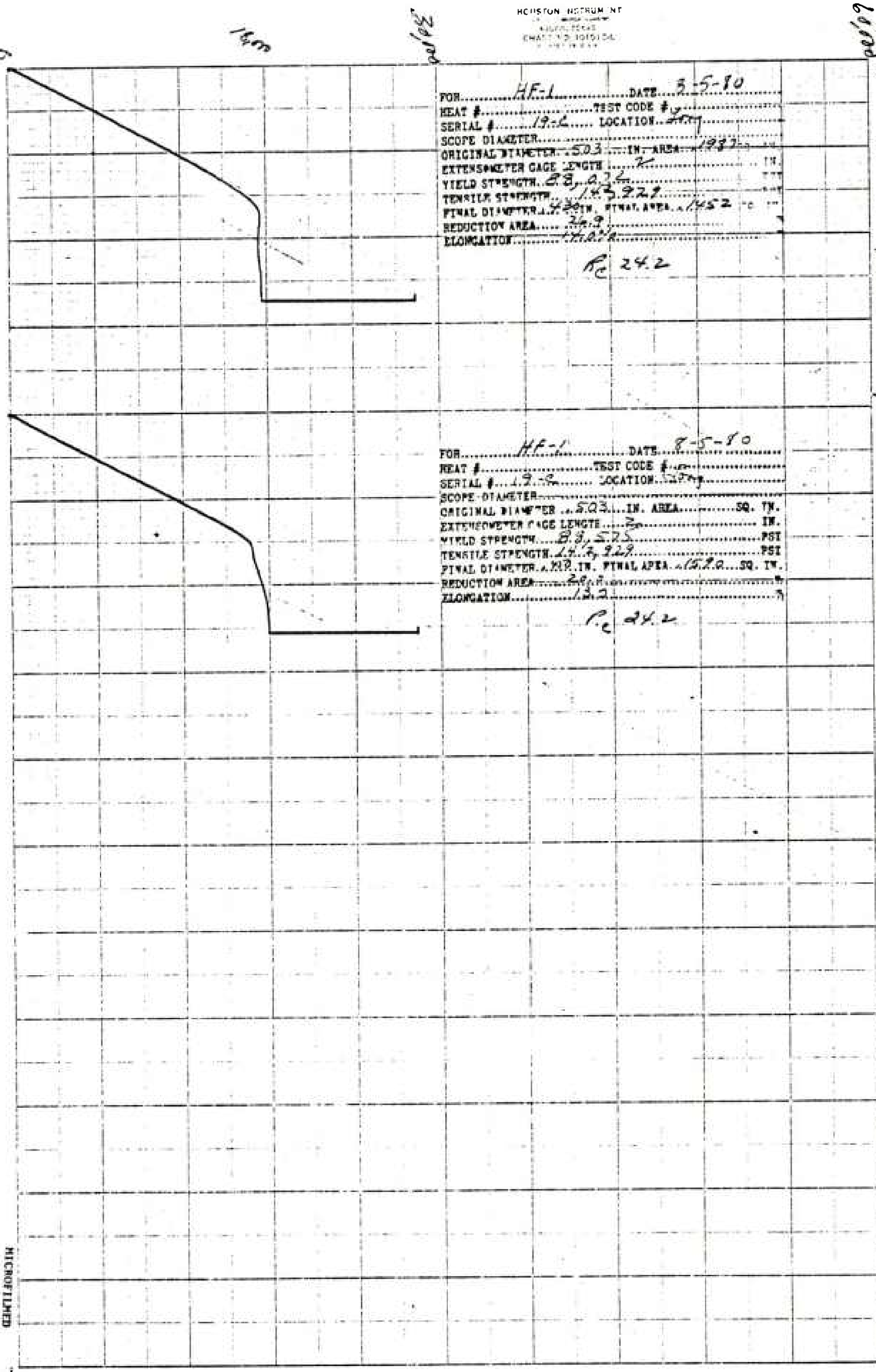
FOR. HE-1 DATE 8/19/80
HEAT #. TEST CODE # 2
SERIAL # 22 LOCATION Long
SCOPE DIAMETER.
ORIGINAL DIAMETER .503 IN. AREA .1987 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 144,155 PSI
TENSILE STRENGTH 184,197 PSI
FINAL DIAMETER .476 IN. FINAL AREA .1780 SQ. IN.
REDUCTION AREA 12.4 %
ELONGATION 8.0 %

R_c 36.3

MICROFILMED 2-27-81

69


HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
0
30,000
60,000
70
FOR HF-1 DATE 8/6/80
HEAT #
TEST CODE #
SERIAL # 10X A
LOCATION Long
SCOPE DIAMETER
ORIGINAL DIAMETER .502 IN. AREA .1979 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 110,756 PSI
TENSILE STRENGTH 156,644 PSI
FINAL DIAMETER .452 IN. FINAL AREA .1605 SQ. IN.
REDUCTION AREA 19.0 %
ELONGATION 10.0 %
Rc 31.4
FOR HF-1 DATE 8/6/80
HEAT #
TEST CODE #
SERIAL # 10X B
LOCATION Long
SCOPE DIAMETER
ORIGINAL DIAMETER .502 IN. AREA .1979 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 111,672 PSI
TENSILE STRENGTH 160,687 PSI
FINAL DIAMETER IN. FINAL AREA SQ. IN.
REDUCTION AREA %
ELONGATION %
Broke at neck
Rc 28.5
HF-1 10x Long. 1500°F 2hrs oil 140°F 1150°F 2hrs
MICROFILMED 2-27-81



FOR.....HF-1.....DATE.....3-5-80
HEAT #.....TEST CODE #.....
SERIAL #.....19-2..... LOCATION.....Long
SCOPE DIAMETER.....
ORIGINAL DIAMETER.....503.....IN. AREA.....1987.....
EXTENSOMETER GAGE LENGTH.....2.....IN.
YIELD STRENGTH.....88,032.....
TENSILE STRENGTH.....143,929.....
FINAL DIAMETER.....430.....IN. FINAL AREA.....1452.....
REDUCTION AREA.....26.9.....
ELONGATION.....14.0%.....

Rc 24.2

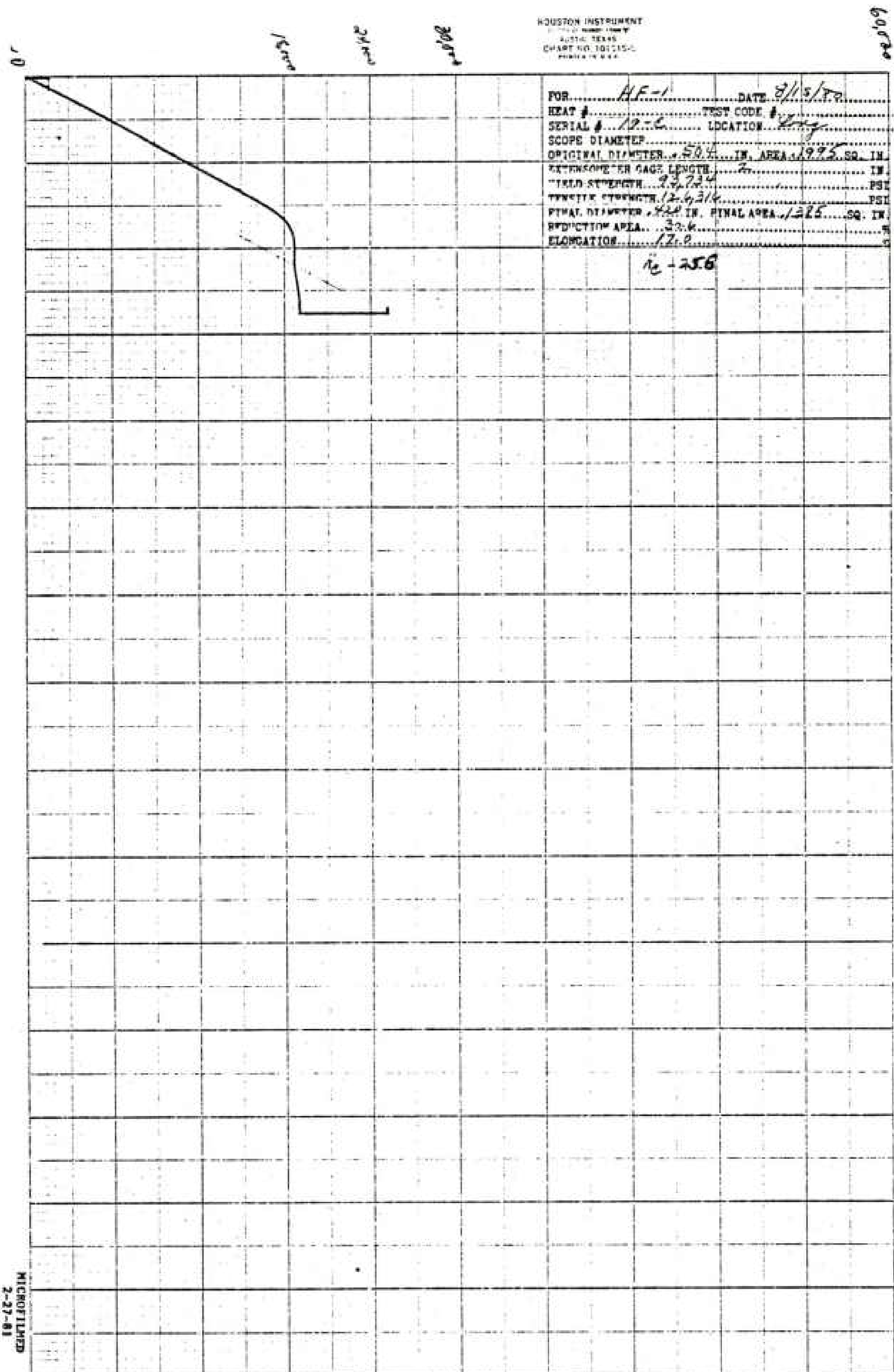
FOR.....HF-1.....DATE.....8-5-80
HEAT #.....TEST CODE #.....
SERIAL #.....19-2..... LOCATION.....Long
SCOPE DIAMETER.....
ORIGINAL DIAMETER.....503.....IN. AREA.....SQ. IN.
EXTENSOMETER GAGE LENGTH.....2.....IN.
YIELD STRENGTH.....83,525.....PSI
TENSILE STRENGTH.....147,929.....PSI
FINAL DIAMETER.....440.....IN. FINAL AREA.....1520.....SQ. IN.
REDUCTION AREA.....23.5.....%
ELONGATION.....13.2.....%

Rc 24.2

HF-1 19-2 3rd Long. 1500°F 2hrs Oil 140°F 1400°F 2hrs

MICROFILMED 2-27-81

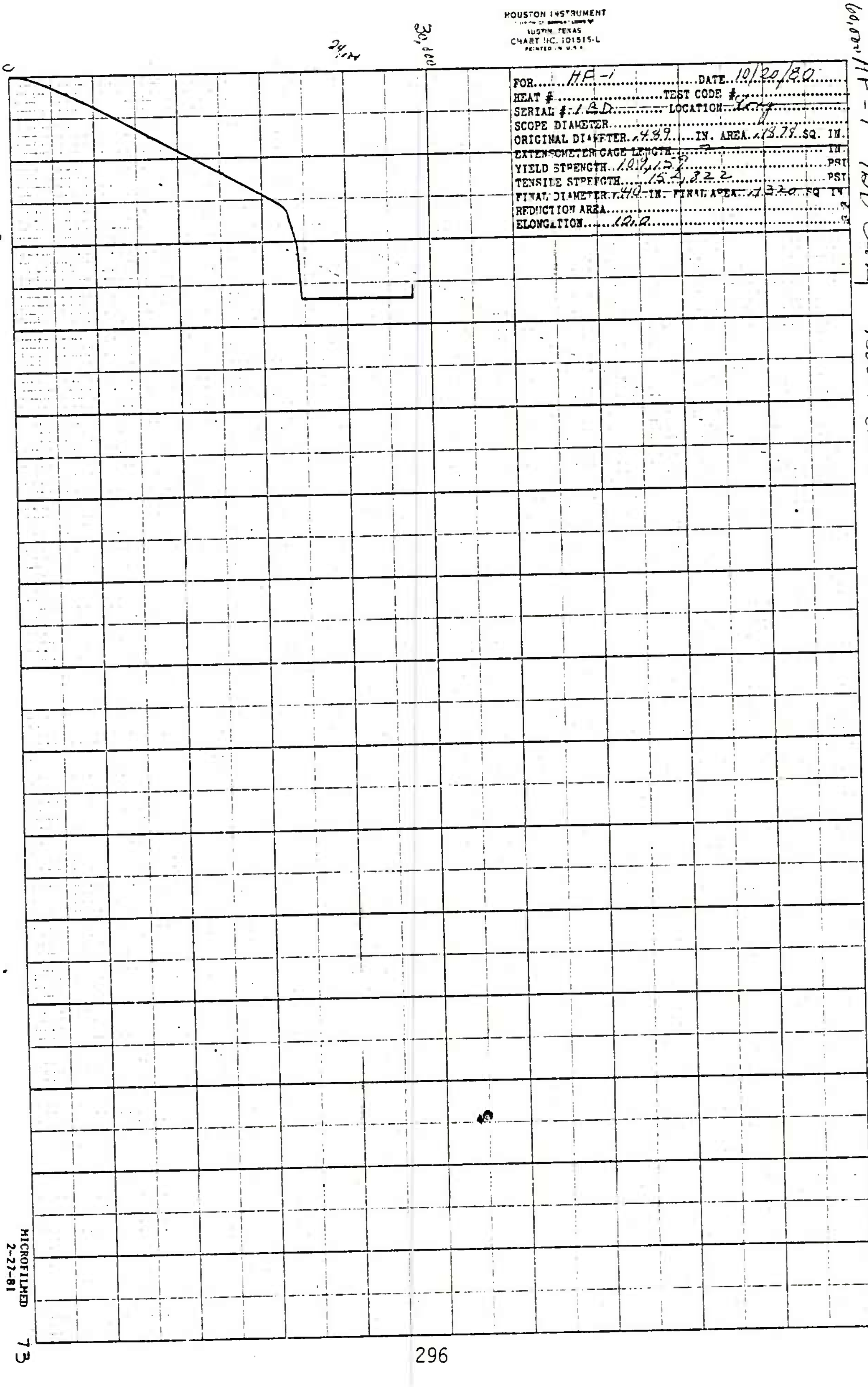
71



HF-1 1- 17-C Long. 1500°F 2hrs oil ... 50°F 1300°F 2 hrs

MICROFILMED 2-27-81

72

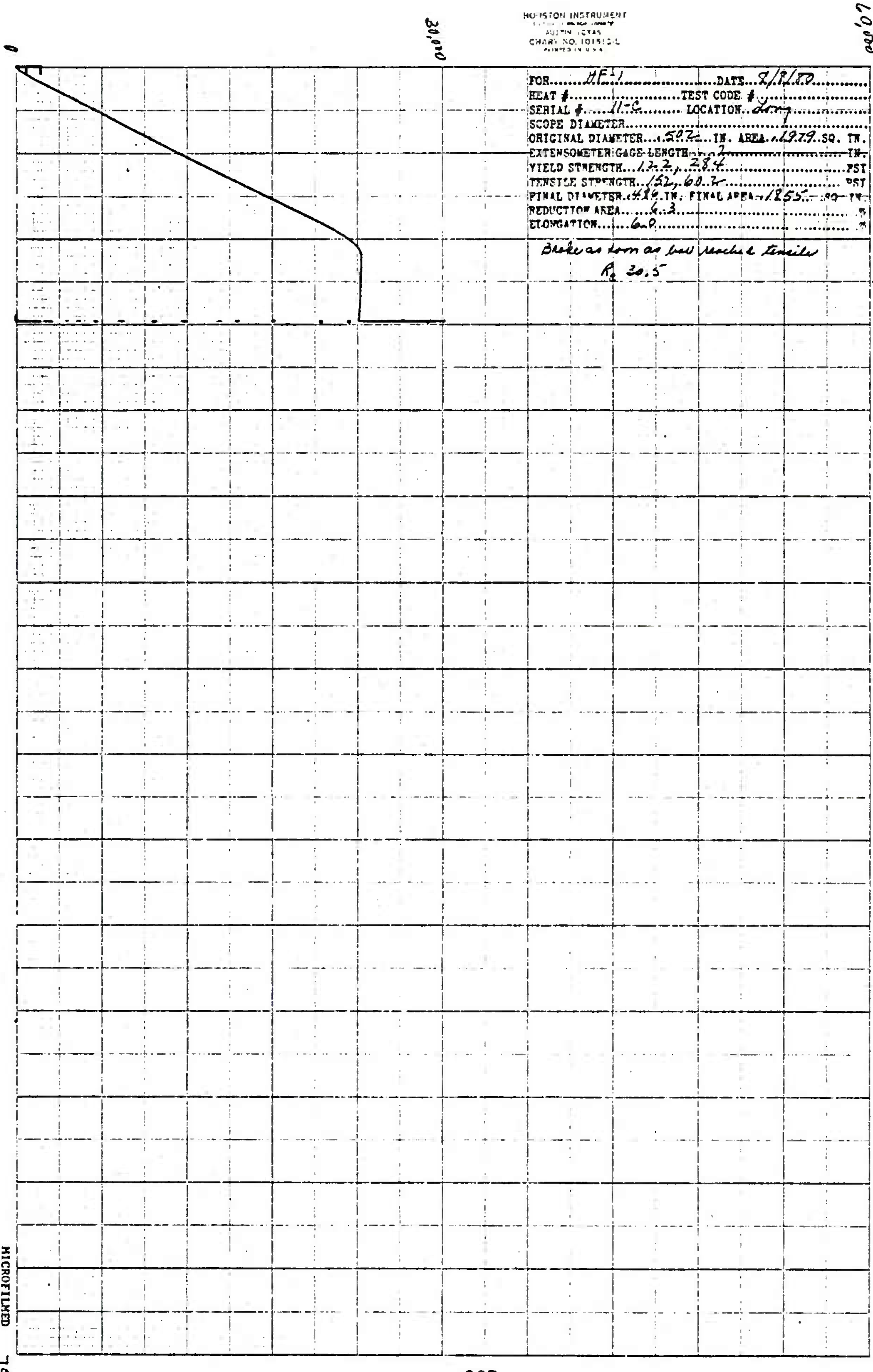


60,000 HF-1 1BD Long 1500°F 2hrs oil cool 1500°F 1125°F 2hrs

MICROFILMED 2-27-81

73

HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
PRINTED IN U.S.A.

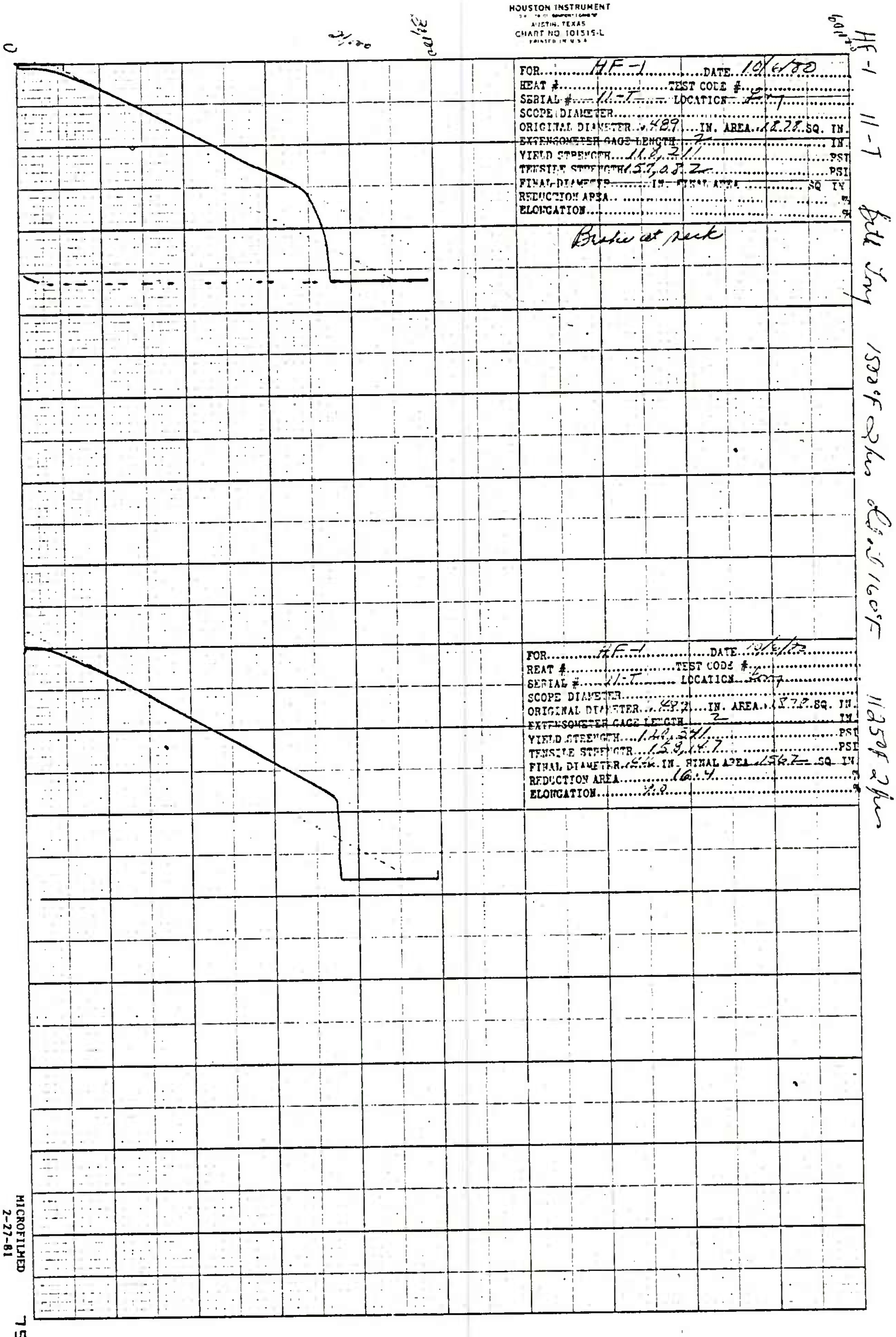


FOR.....HF-1.....DATE.....8/18/80.....
HEAT #.....TEST CODE #.....
SERIAL #.....11-C.....LOCATION.....Long.....
SCOPE DIAMETER.....
ORIGINAL DIAMETER.....502.....IN. AREA.....1979.....SQ. IN.
EXTENSOMETER GAGE LENGTH.....2.....IN.
YIELD STRENGTH.....122,284.....PSI
TENSILE STRENGTH.....152,602.....PSI
FINAL DIAMETER.....486.....IN. FINAL AREA.....1855.....SQ. IN.
REDUCTION AREA.....6.3.....%
ELONGATION.....6.0.....%

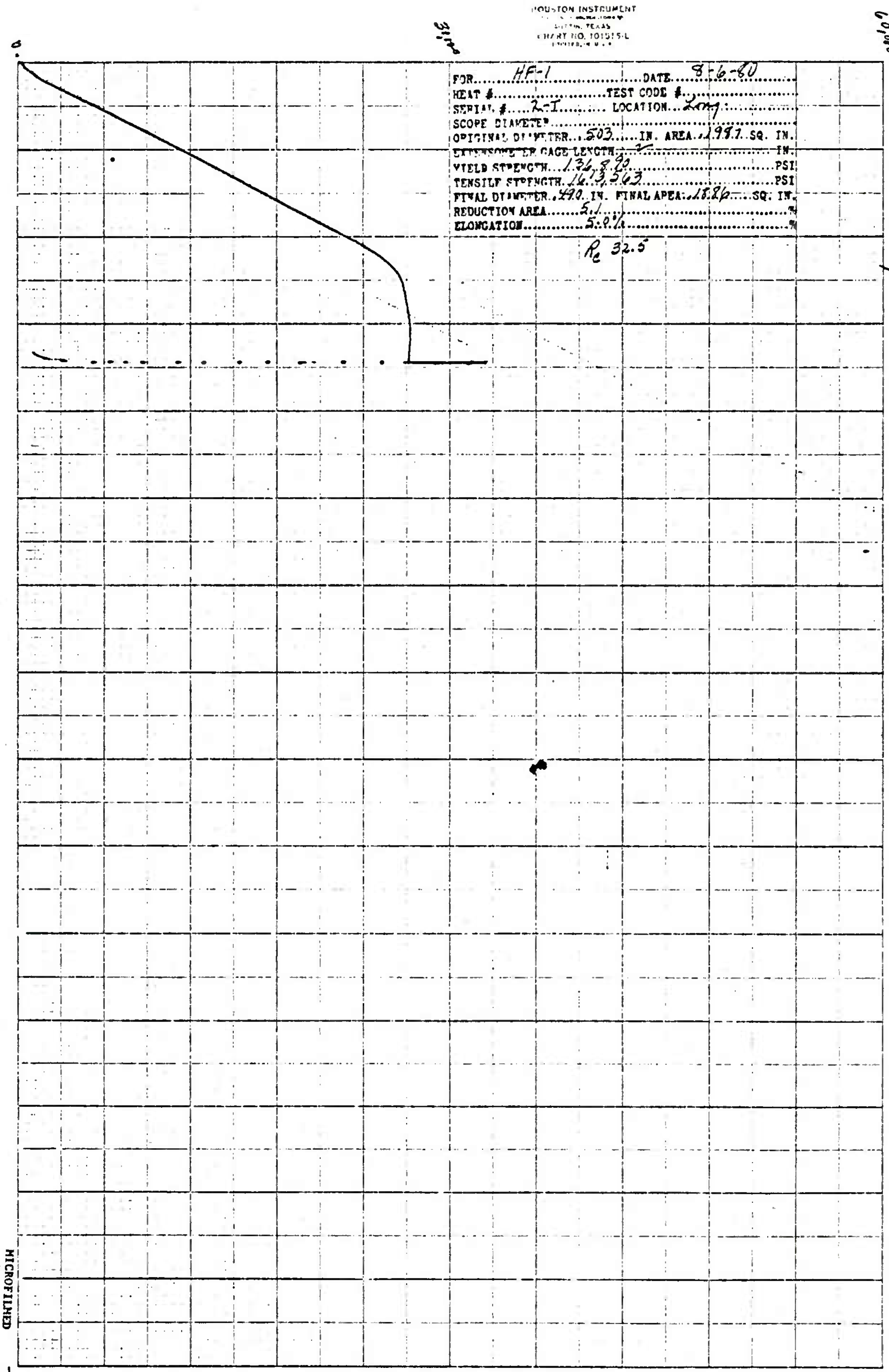
Broke as soon as bar reached tensile
R_c 30.5

HF-1 11-C Long 1500°F 2½ hrs [illegible] 150° 1125°F 2 hrs

MICROFILMED
2-27-81

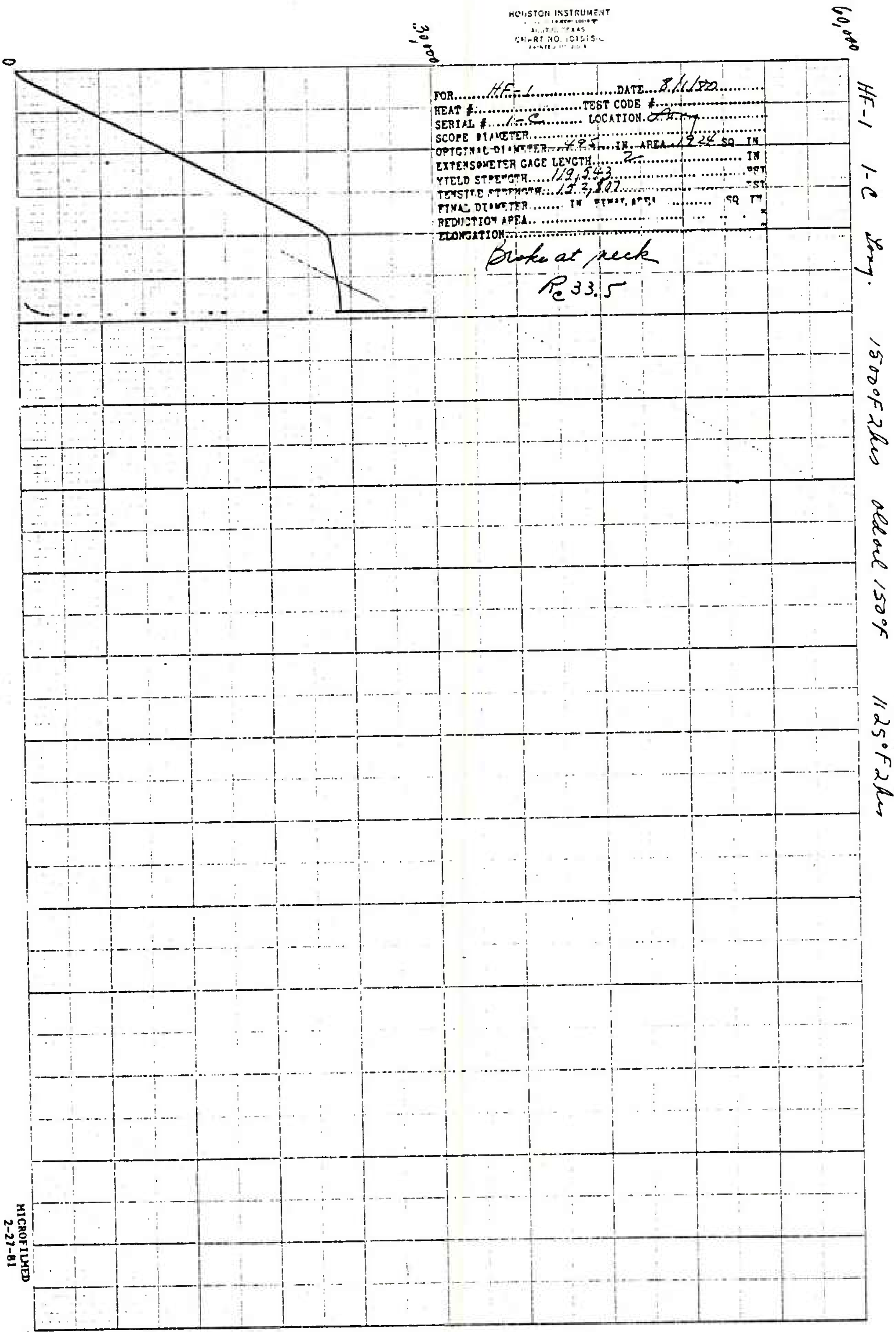


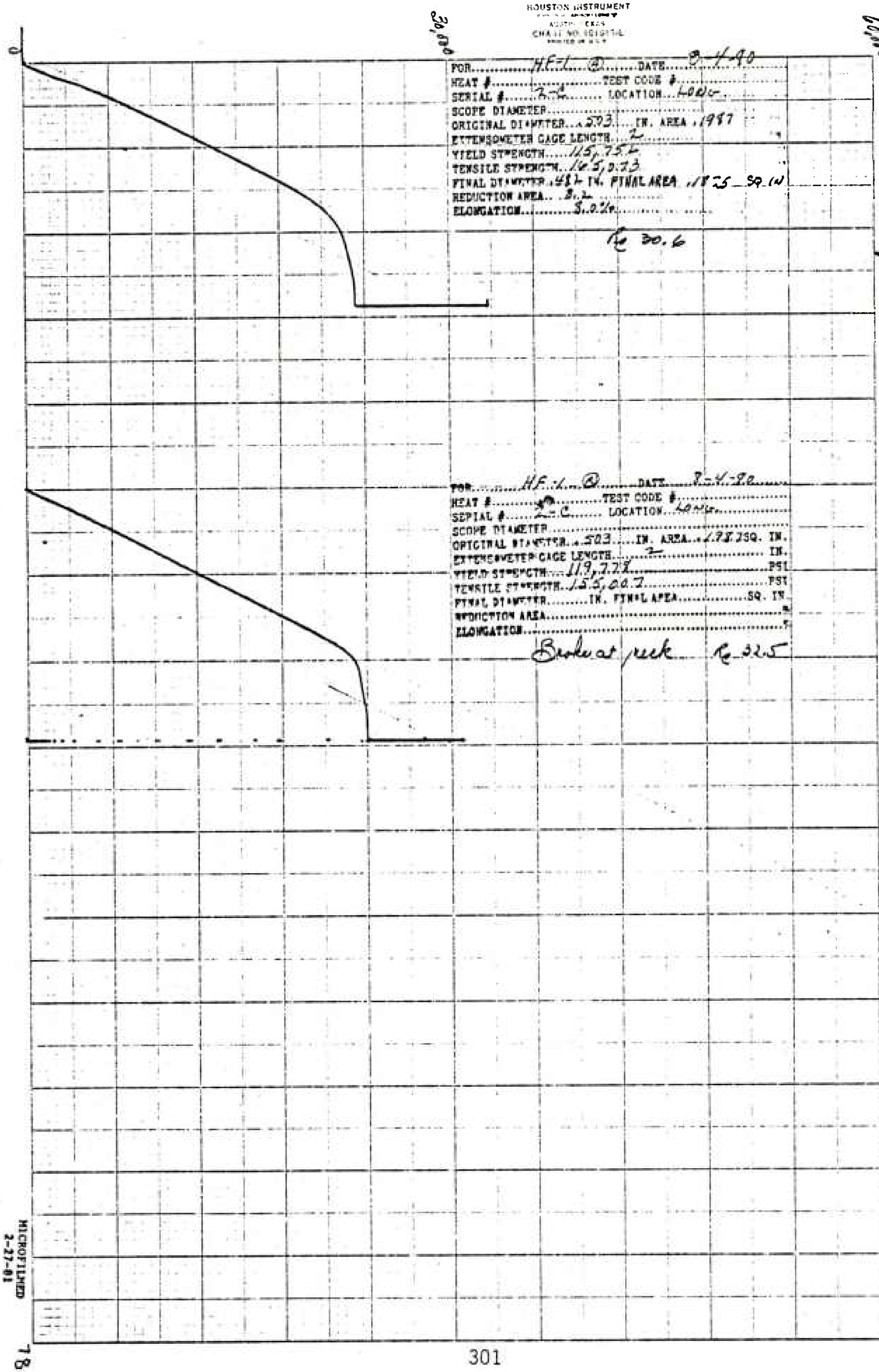
HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
PRINTED IN U.S.A.
0
FOR HF-1 DATE 10/6/80
HEAT # TEST CODE #
SERIAL # 11-T LOCATION
SCOPE DIAMETER
ORIGINAL DIAMETER .489 IN. AREA SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 118,211 PSI
TENSILE STRENGTH 157,082 PSI
FINAL DIAMETER IN. FINAL AREA SQ. IN.
REDUCTION AREA %
ELONGATION %
Broke at neck
HF-1 11-T
FOR HF-1 DATE
HEAT # TEST CODE #
SERIAL # 11-T LOCATION
SCOPE DIAMETER
ORIGINAL DIAMETER IN. AREA SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH PSI
TENSILE STRENGTH 153,147 PSI
FINAL DIAMETER IN. FINAL AREA SQ. IN.
REDUCTION AREA 16.4 %
ELONGATION %
75



HF-1 2-T Long 1500°F 2hrs air cool 1500°F 1125°F 2hrs

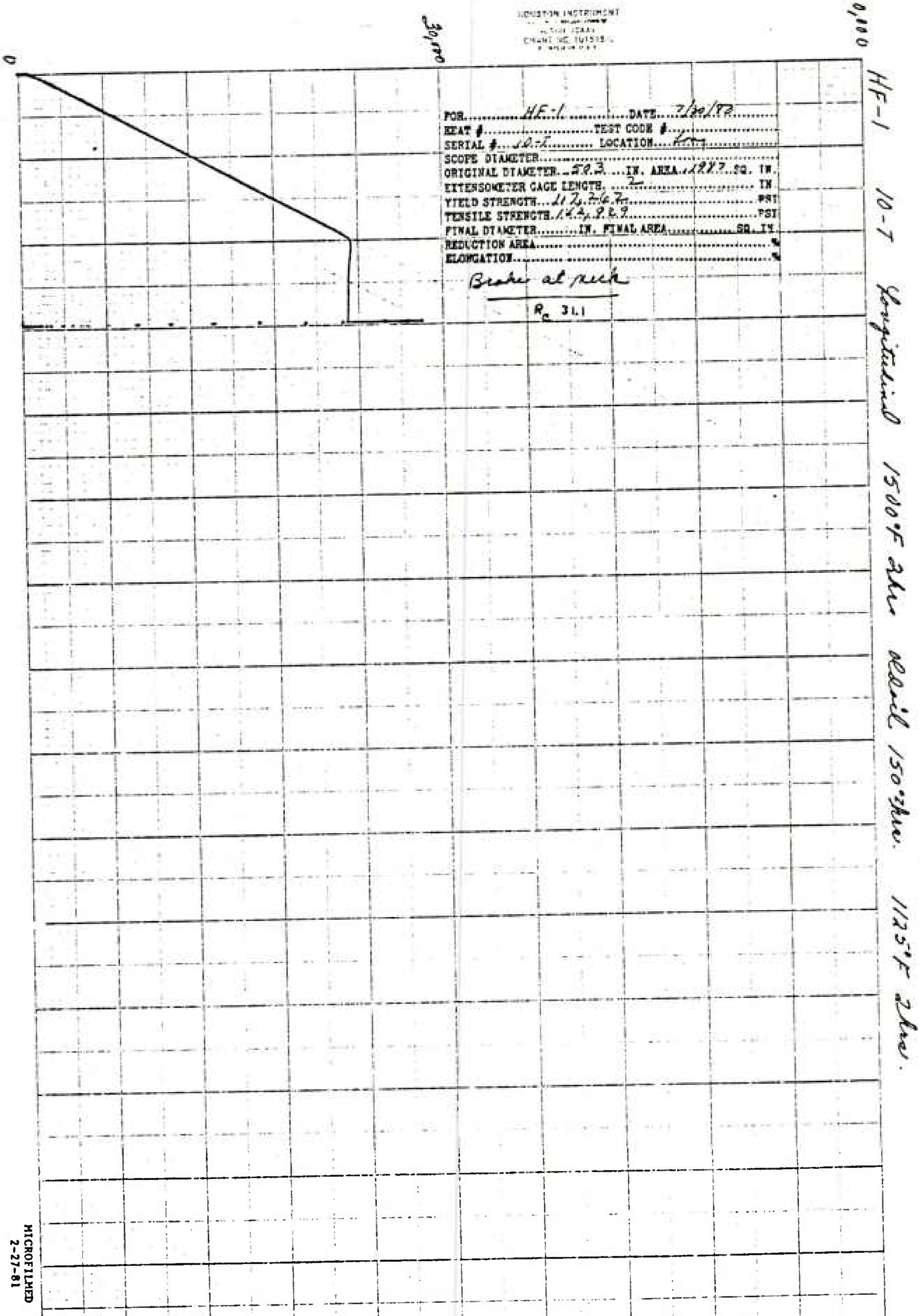
76


HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO.
0
30,000
60,000
FOR....HF-1....DATE....8/1/80
HEAT #....TEST CODE #
SERIAL #....1-C....LOCATION....Long
SCOPE DIAMETER
ORIGINAL DIAMETER....425....IN. AREA....1924 SQ. IN.
EXTENSOMETER GAGE LENGTH....2....IN
YIELD STRENGTH....119,543....PSI
TENSILE STRENGTH....123,807....PSI
FINAL DIAMETER....IN. FINAL AREA....SQ. IN.
REDUCTION AREA
ELONGATION
Broke at neck
Rc 33.5
HF-1 1-C Long. 1500°F 2hrs oil cool 150°F 1125°F 2hrs
77

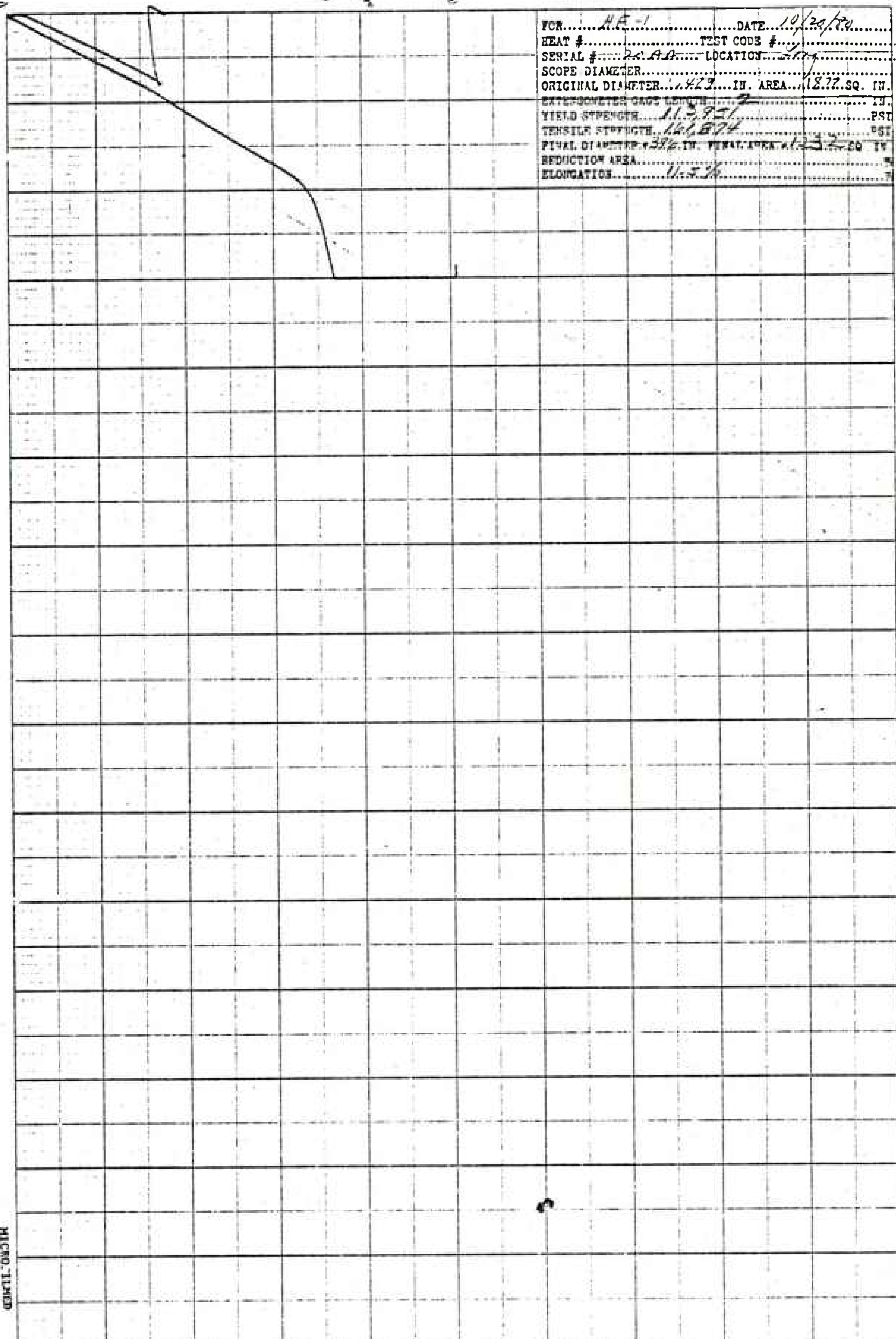


HF-1 2C Long. 1500°F 2hr oil 140°F 1100°F 2hrs

MICROFILMED
2-27-81

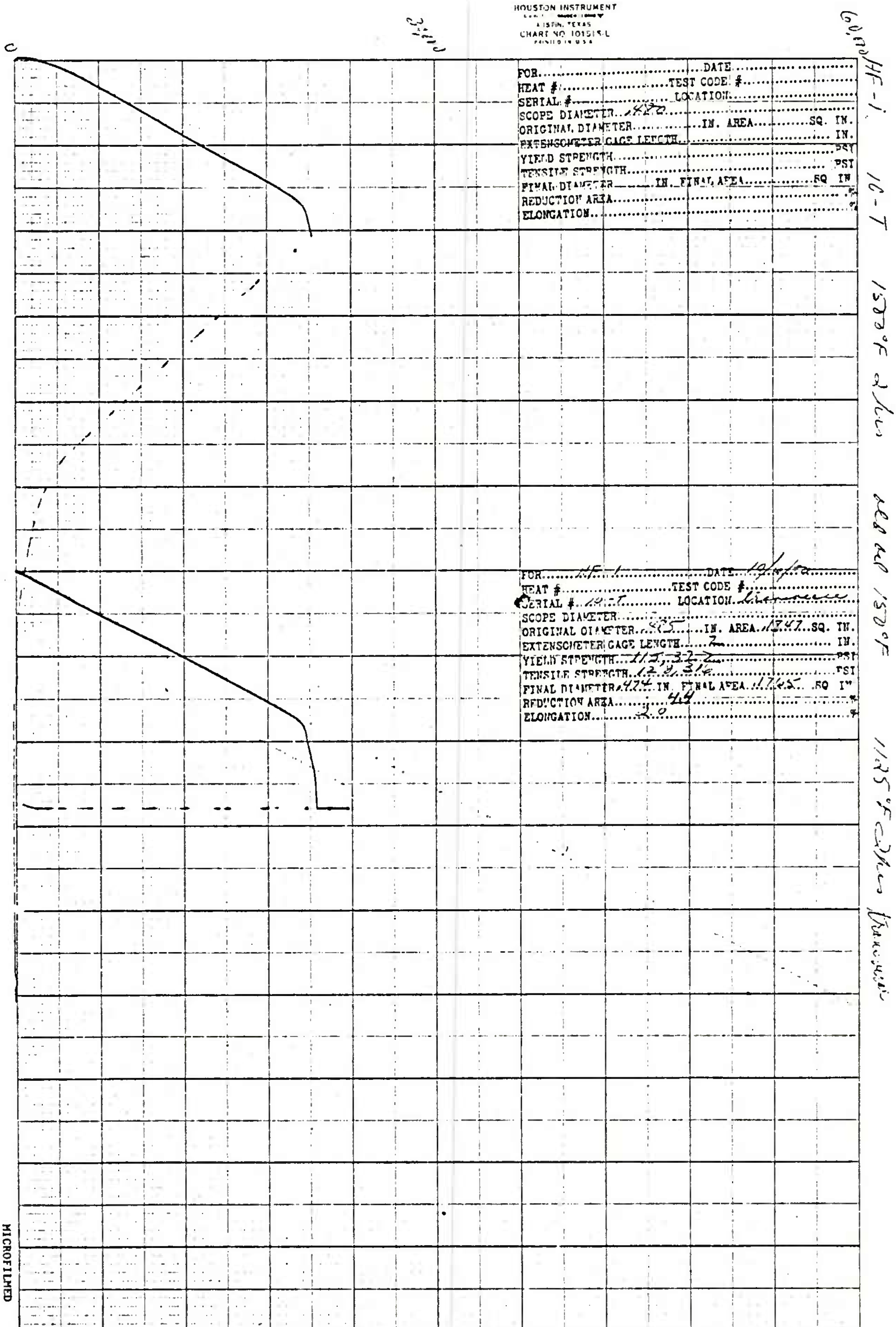

HOUSTON INSTRUMENT
CHART NO. 1015151
0
30,000
60,000
FOR HE-1 DATE 7/20/82
HEAT # TEST CODE #
SERIAL # 10-T LOCATION Long
SCOPE DIAMETER
ORIGINAL DIAMETER .503 IN. AREA .1987 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN
YIELD STRENGTH 117,267 PSI
TENSILE STRENGTH 142,929 PSI
FINAL DIAMETER IN. FINAL AREA SQ. IN
REDUCTION AREA %
ELONGATION %
Broke at neck
R_c 31.1
HF-1 10-T Longitudinal 1500°F 2hrs Oil 150°thru. 1125°F 2hrs
79

HOUSTON INSTRUMENT
AUSTIN TEXAS
CHART NO. [illegible]



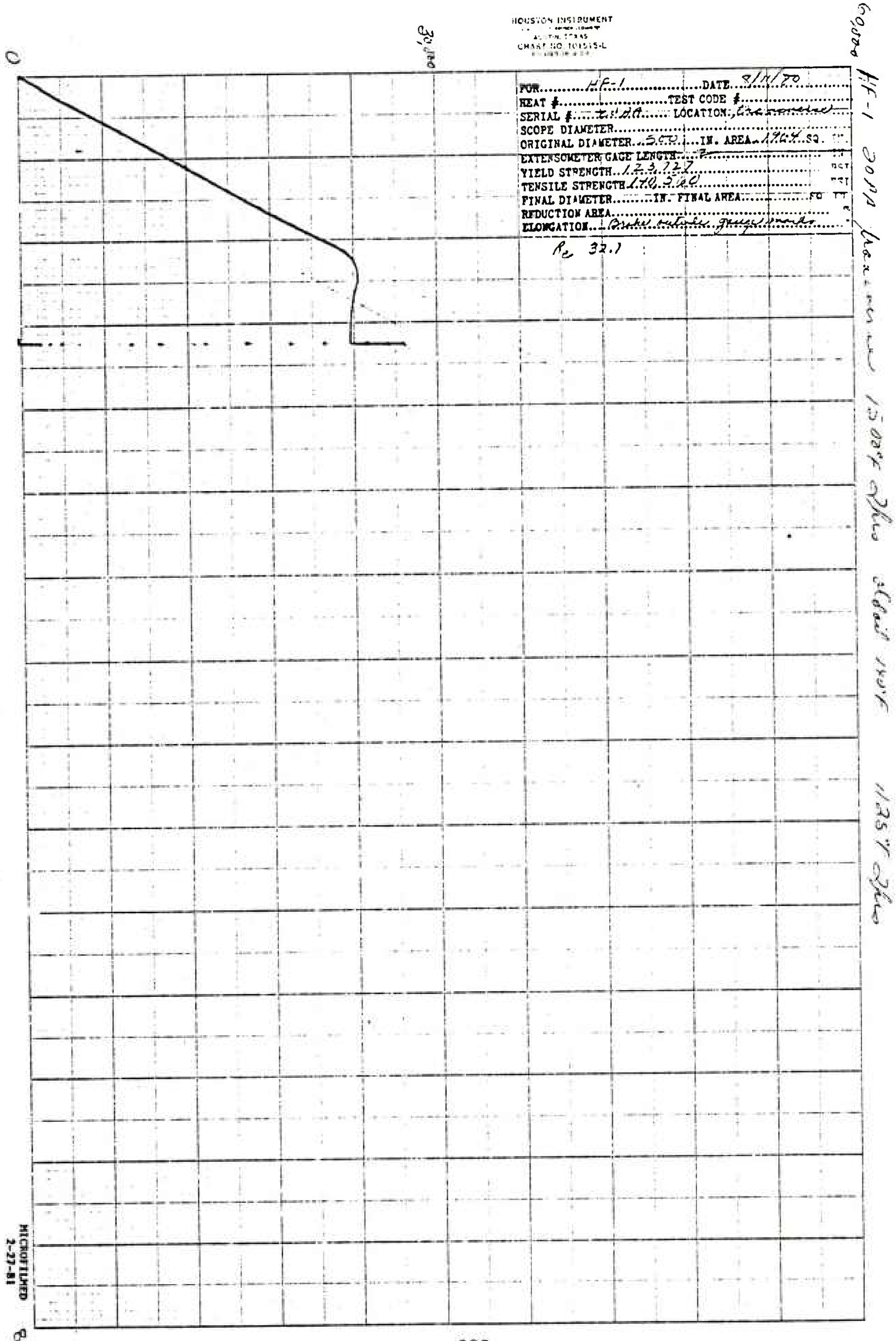
20AA Long 1570°F 2 hr 1125°F 2 hr oiled 150°F

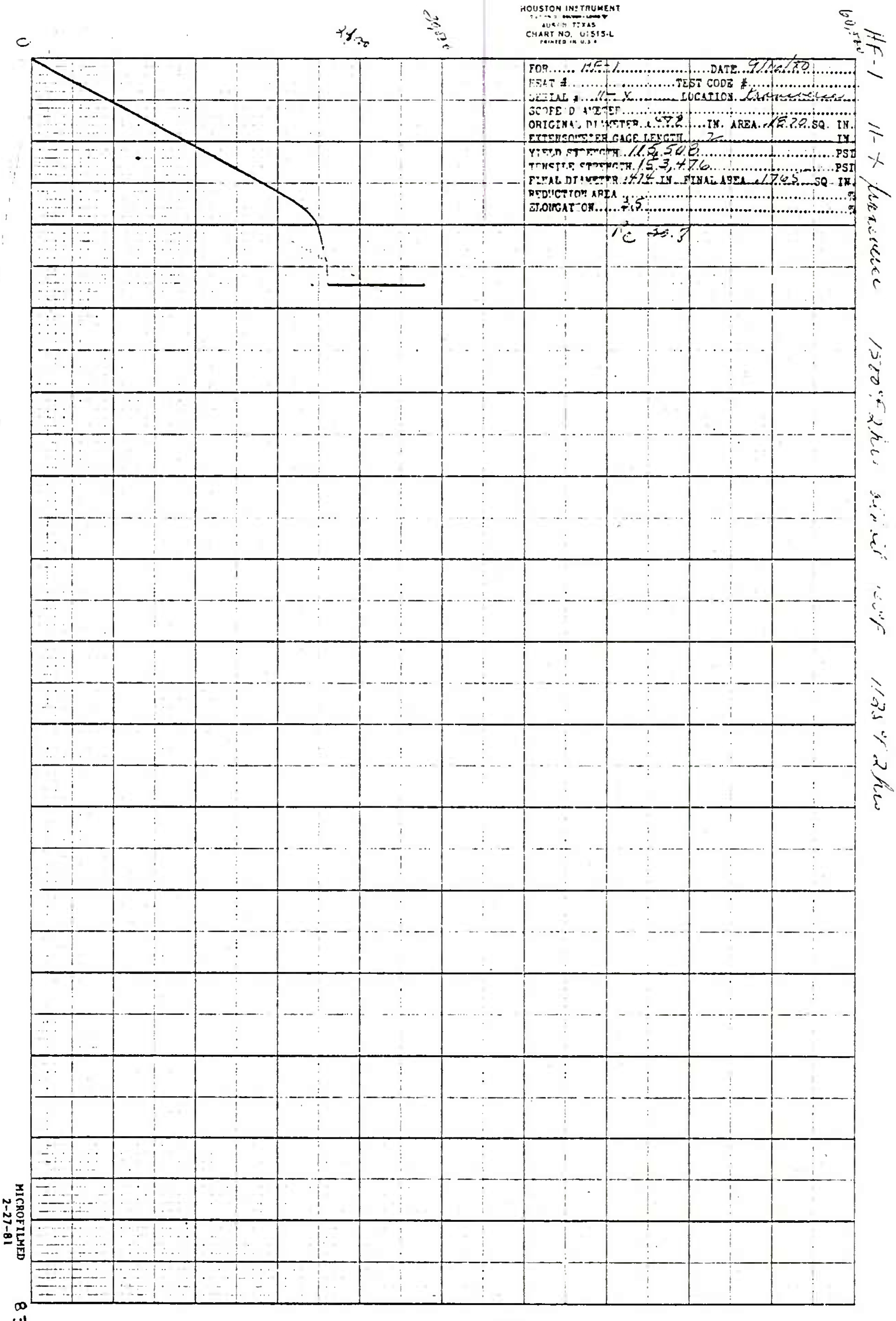
MICRO-FILMED
2-27-81



MICROFILMED 2-27-81

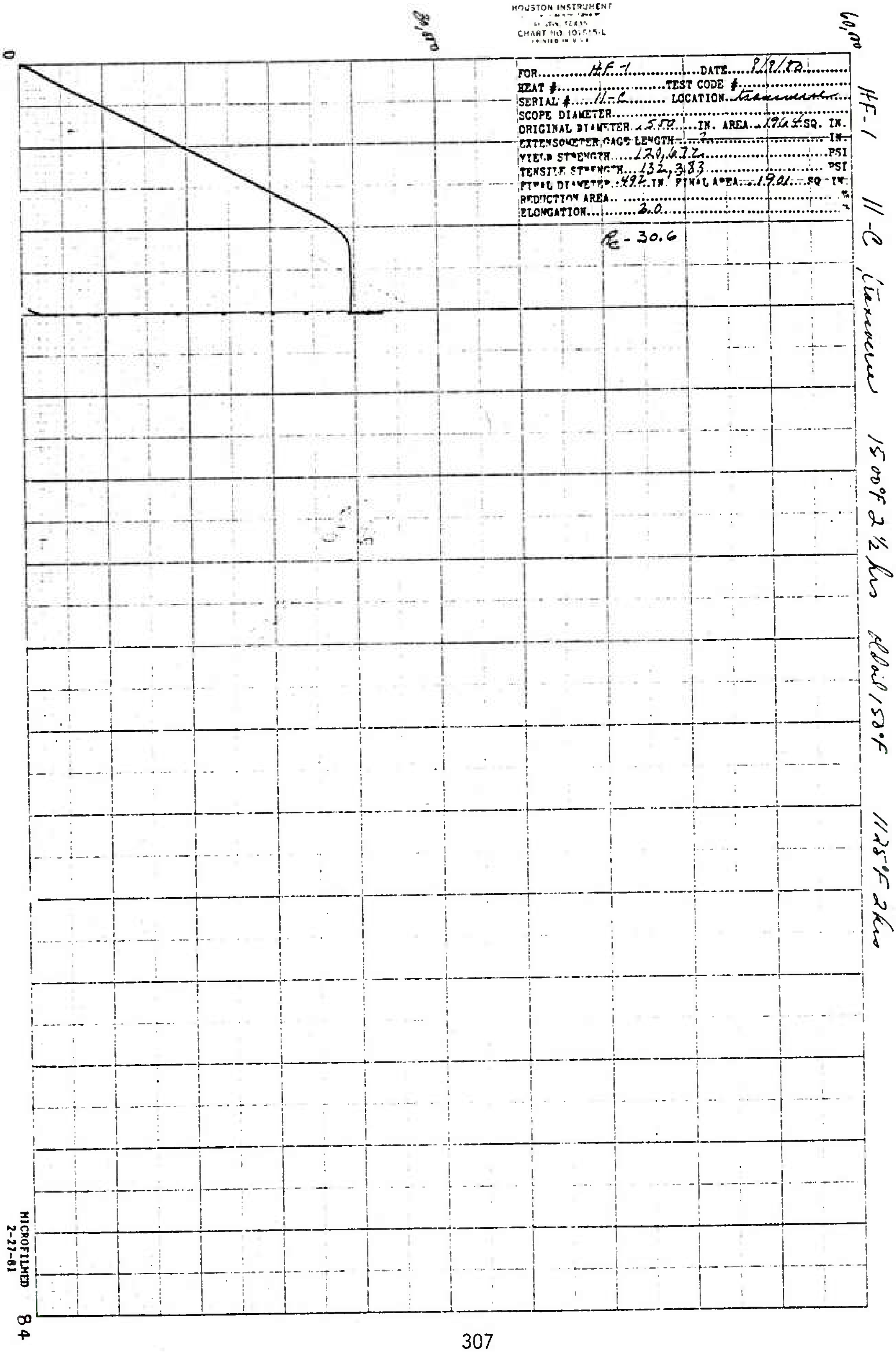
81

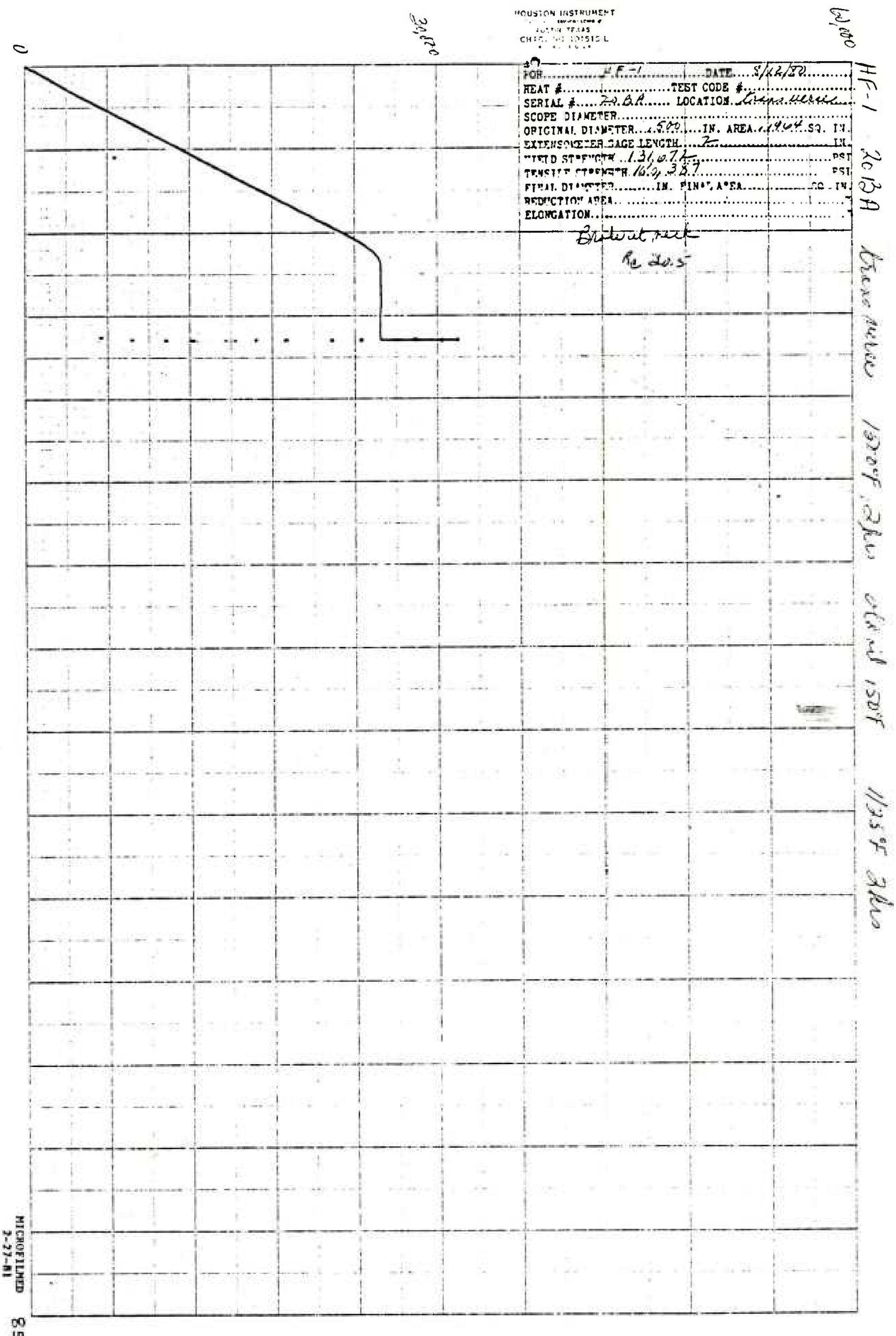

HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
0
30,000
60,000
FOR HF-1 DATE 8/11/70
HEAT # TEST CODE #
SERIAL #
SCOPE DIAMETER
ORIGINAL DIAMETER .500 IN. AREA .1964 SQ. IN.
EXTENSOMETER GAGE LENGTH
YIELD STRENGTH 123,727 PSI
TENSILE STRENGTH 170,300 PSI
FINAL DIAMETER IN. FINAL AREA SQ. IN.
REDUCTION AREA
ELONGATION
R_c 32.1
HF-1
82

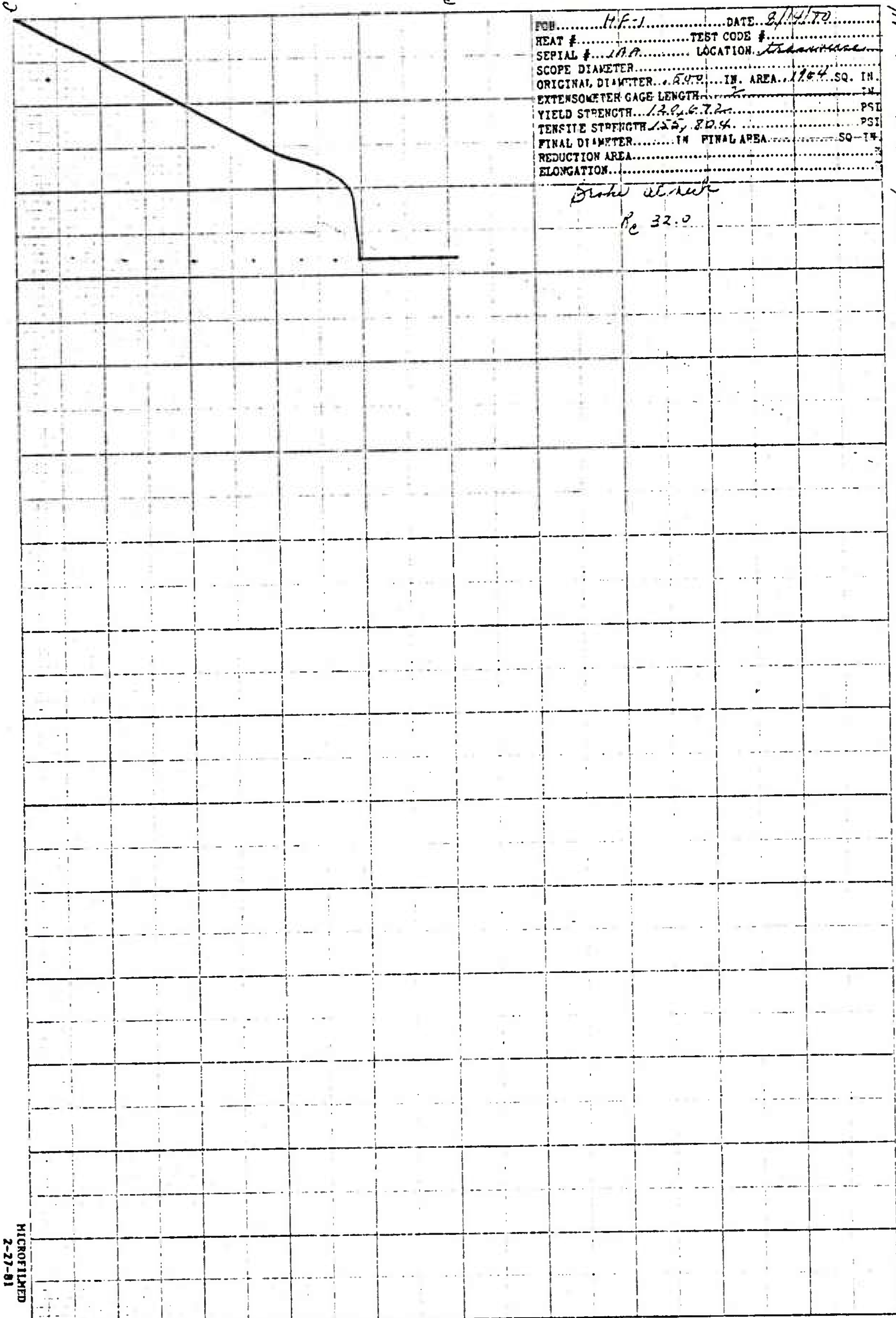

HOUSTON INSTRUMENT
AUSTIN TEXAS
CHART NO. 01515-L
FOR HF-1 DATE 9/ /80
HEAT # TEST CODE #
SERIAL # 11-X LOCATION transverse
SCOPED DIAMETER
ORIGINAL DIAMETER .472 IN. AREA .1820 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 115,500 PSI
TENSILE STRENGTH 153,476 PSI
FINAL DIAMETER .474 IN. FINAL AREA .1765 SQ. IN.
REDUCTION AREA %
ELONGATION 4.5 %
R_c 30.7
HF-1 11-X transverse 1500°F 2hrs
1125°F 2hrs
60,500
0
83

HOUSTON INSTRUMENT

CHART NO. 10515-L



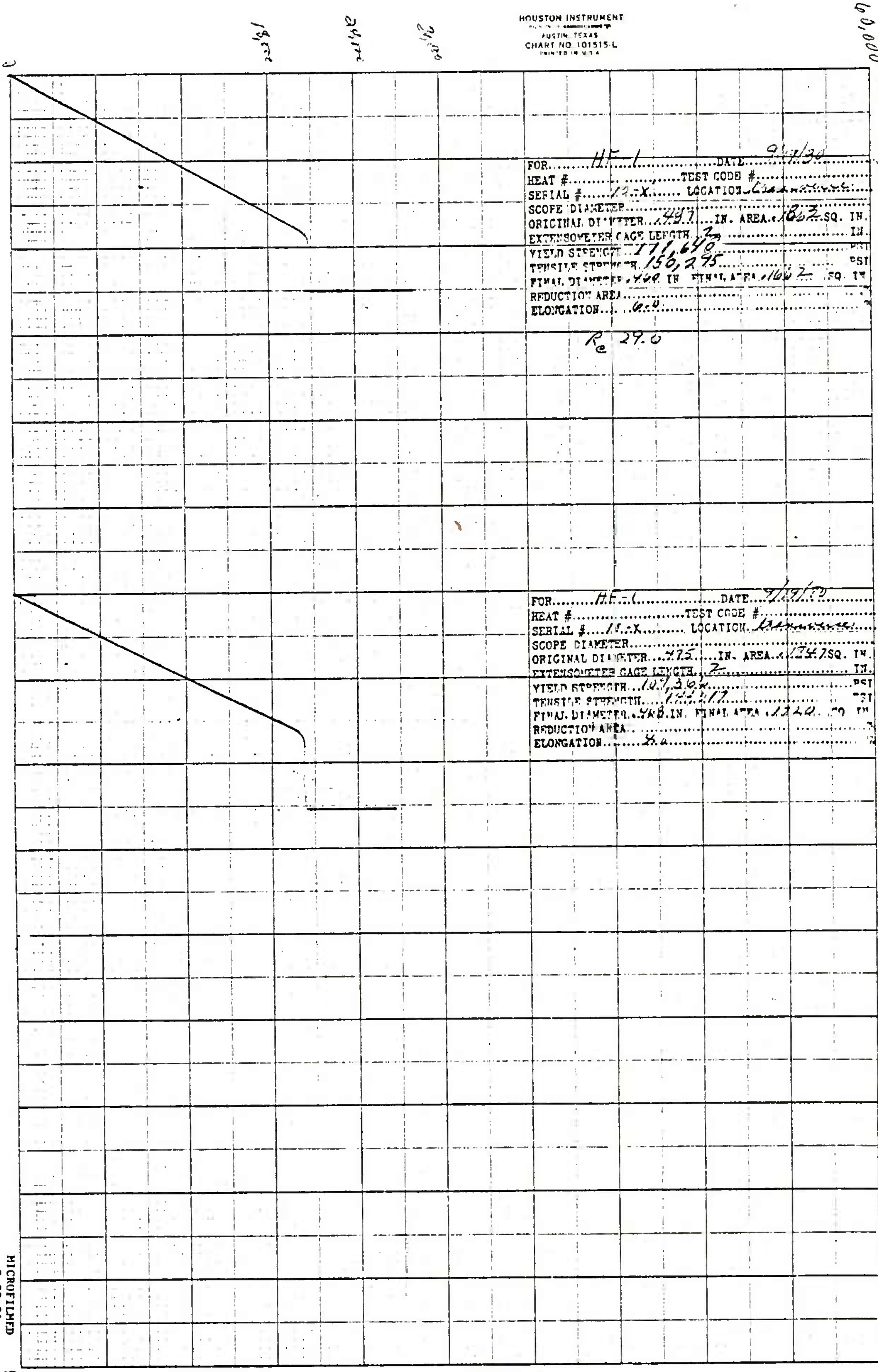

HOUSTON INSTRUMENT
AUSTIN TEXAS
FOR H.F-1 DATE 5/22/80
HEAT # TEST CODE #
SERIAL # 20 BR LOCATION Transverse
SCOPE DIAMETER
ORIGINAL DIAMETER .500 IN. AREA .1964 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 131,072 PSI
TENSILE STRENGTH 162,387 PSI
FINAL DIAMETER IN. FINAL AREA SQ. IN.
REDUCTION AREA
ELONGATION
Broke at neck
Rc 20.5
0
30,000
60,000
HF-1 2C13A
1300F 2hr
1125F 2hr
MICROFILMED 3-27-81
85



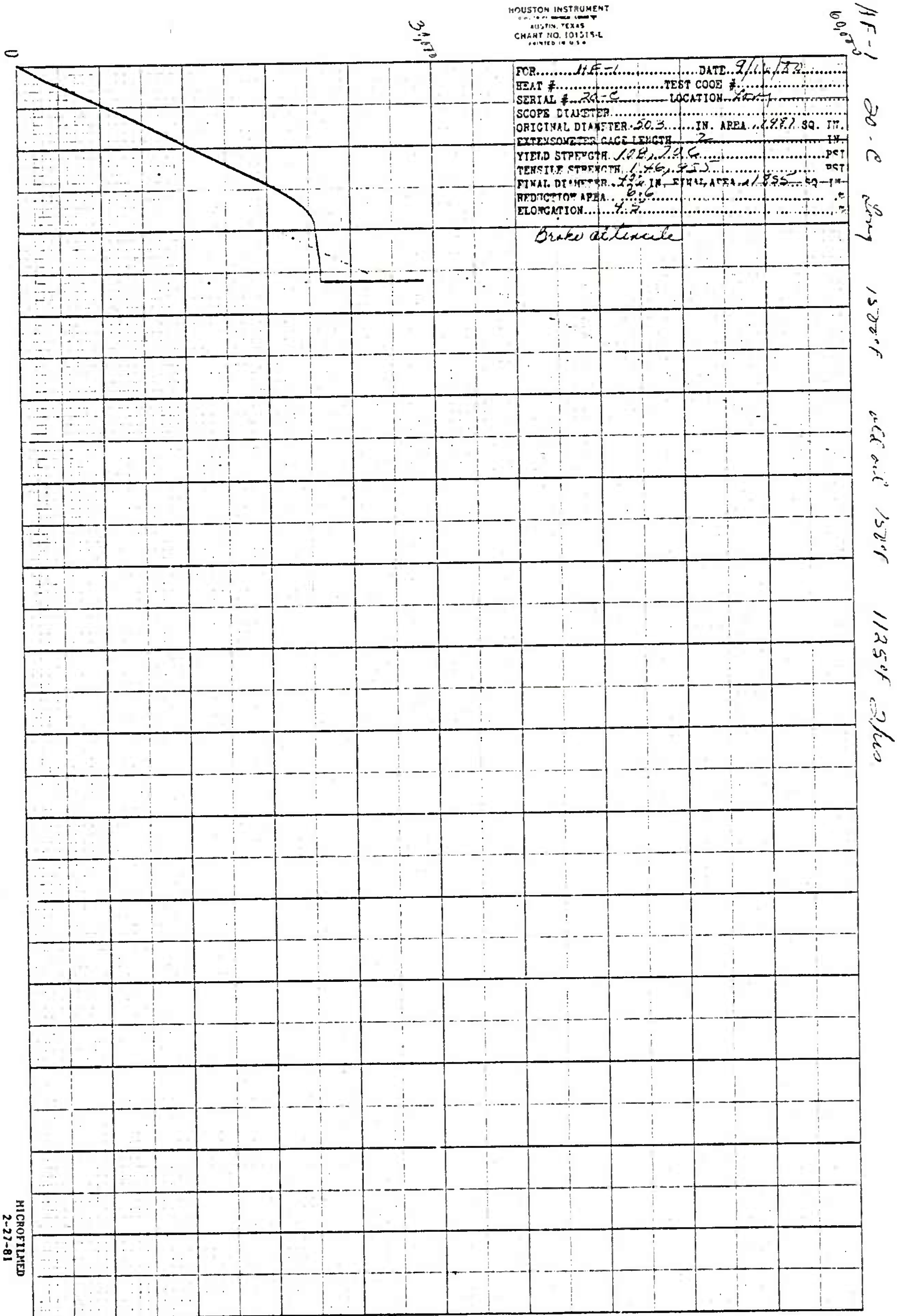
MICROFILMED 2-27-81

86

HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
PRINTED IN U.S.A.

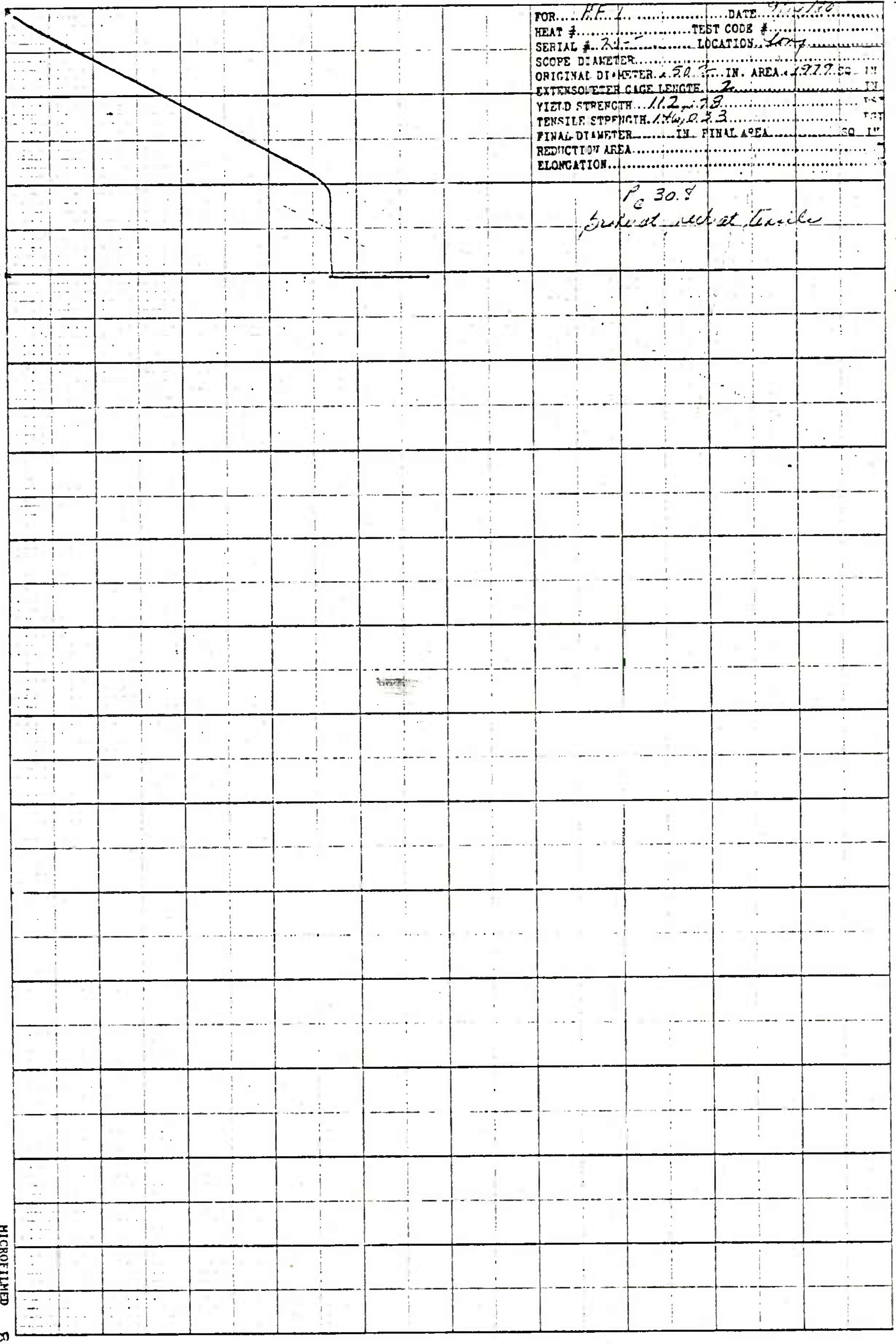


HF-1 10X 1500°F 3hrs 1550°F 1025°F 2hrs


0
31,650
HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-L
PRINTED IN U.S.A.
FOR ME-1 DATE 9/14/72
HEAT # TEST CODE #
SERIAL # 20-C LOCATION Long
SCOPE DIAMETER
ORIGINAL DIAMETER .503 IN. AREA .1987 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 108,796 PSI
TENSILE STRENGTH 146,950 PSI
FINAL DIAMETER .494 IN. FINAL AREA .1855 SQ. IN.
REDUCTION AREA 6.6 %
ELONGATION 4.7 %
Broke at tensile
ME-1 20-C Long 1500°F Old oil 1500°F 1125°F 2/hrs
6000#

88

HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO. 101515-C



MICROFILMED
2-27-81

89

HF-1
Republic Steel

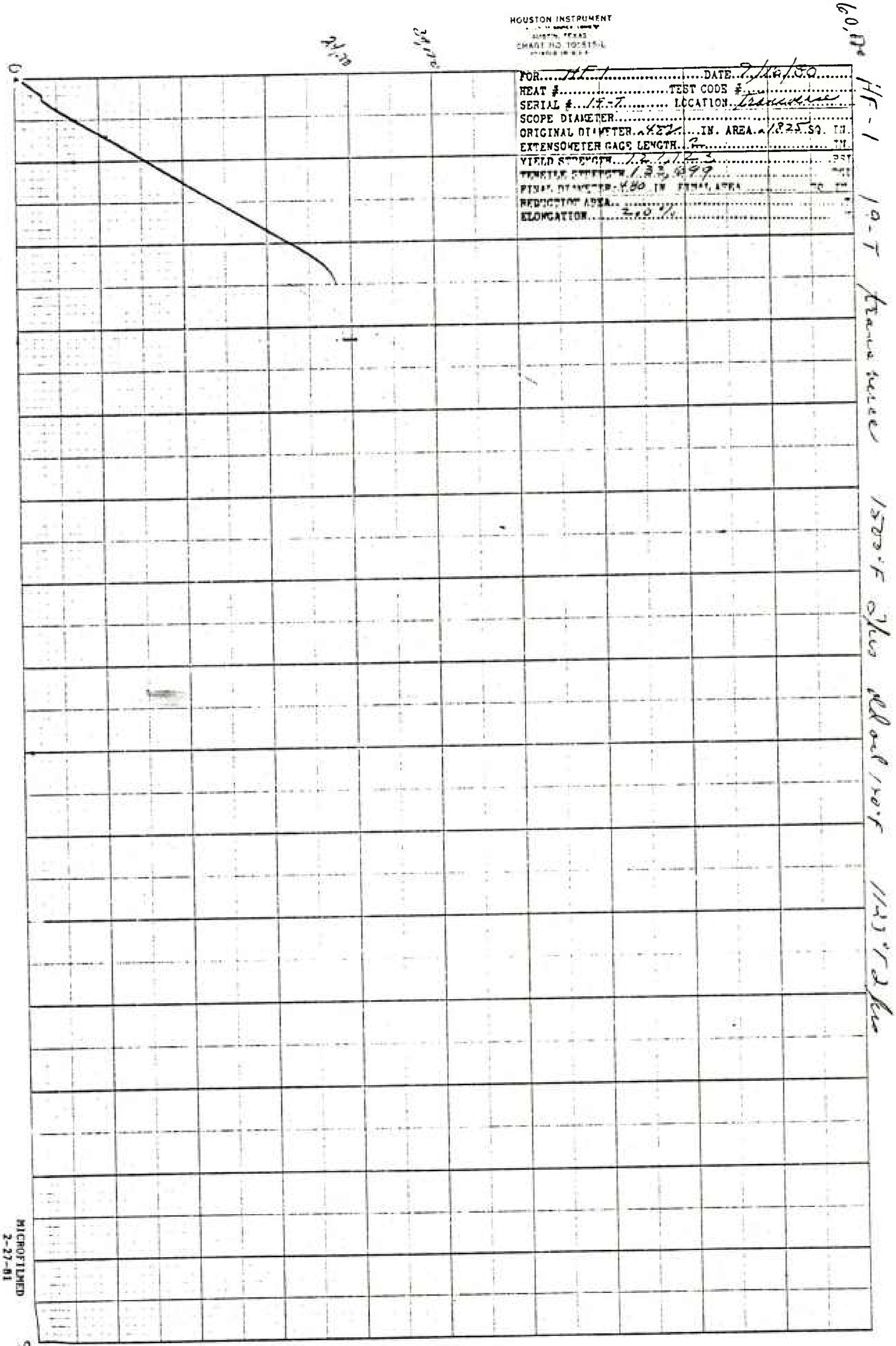
Sample	Heat	Temper	Sect	Yield Strength	Tensile	Elong %	RA	Hardness Rc
20BD	1500	1125°	(T)	128 309	161 914	7.0	10.9	31.9
1 AA	1500	1125°	T	~~120 627~~ 131 000	158 804	4.0 (Broke at Neck)	4.7	32
20BA	"	"	T	131 672	160 387	"		30.5
20AA	"	"	T	123 727	140 560	"		32.7
1 BA	"	"	T	119 654	152 749	4.5		31.8
40 BD	"	"	T	128 819	159 877	7.0	11.7	32
1 BD	"		T	128 309	157 841	6.0	7.8	30.7
40 BA	"		T	116 090	153 767	3.0		31.4
40 AA		"	T	122 199	155 804	4.0	7.8	

20BA	1500	1125	L	123 805	164 066	12.0	22.8	32.9
40BA	"	"	L	117 765	169 099	12.0	24.9	33.6
1 AA	"	"	L	123 005	166 583	12.0	26.9	33.2
1 AA	"	"	L	124 308	168 093	13.0	26.1	34
20BD	1500	"	L	120 785	168 092	12.5	28.3	33.9
~~20 BA~~								
40 BD	"	"	L	116 725	166 751	12.5	24.6	33.4
40 AA	"	"	L	125 818	165 576	12.0	23.5	32.8

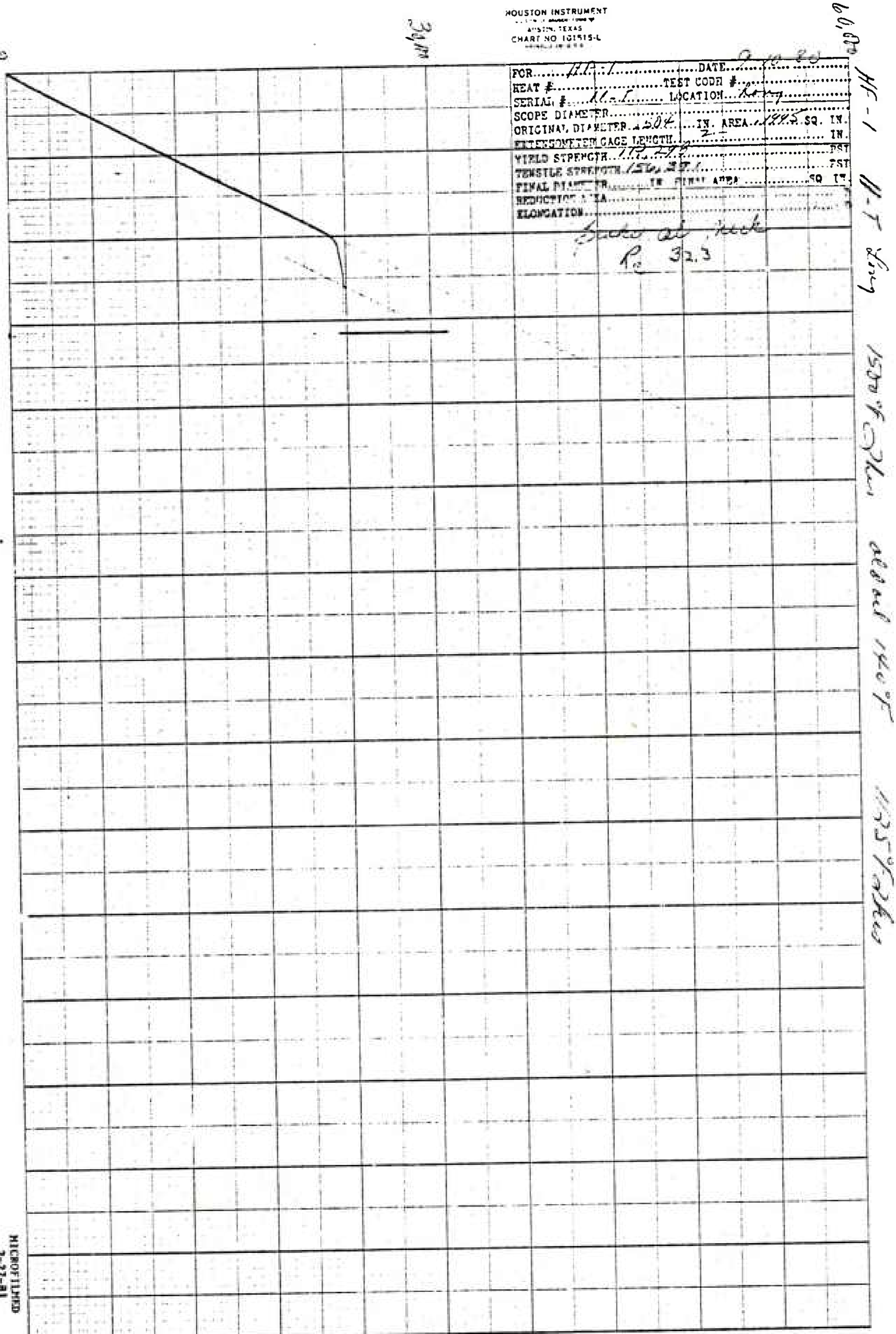
Chamberlain
Where Ideas Become Reality
To
From
Date
Subject

MICROFILMED
2-27-81

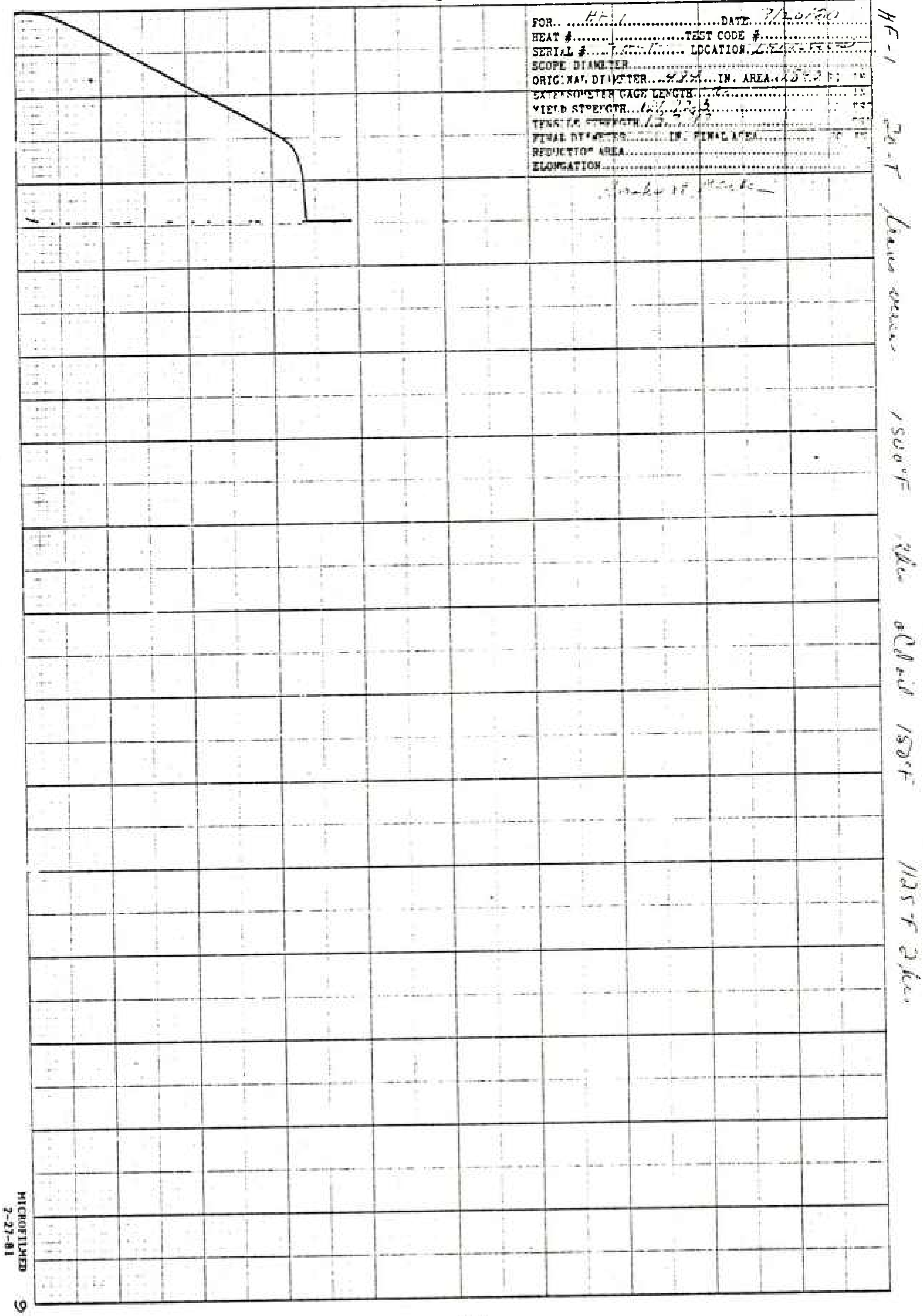
90



HOUSTON INSTRUMENT
AUSTIN, TEXAS
FOR HF-1 DATE 7/16/80
HEAT #
TEST CODE #
SERIAL # 15-T
LOCATION Transverse
SCOPE DIAMETER
ORIGINAL DIAMETER .482 IN. AREA .1825 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 121,123 PSI
TENSILE STRENGTH 133,499 PSI
FINAL DIAMETER .480 IN
REDUCTION AREA
ELONGATION 2.0 %
60,000
HF-1
15-T
MICROFILMED 2-27-81

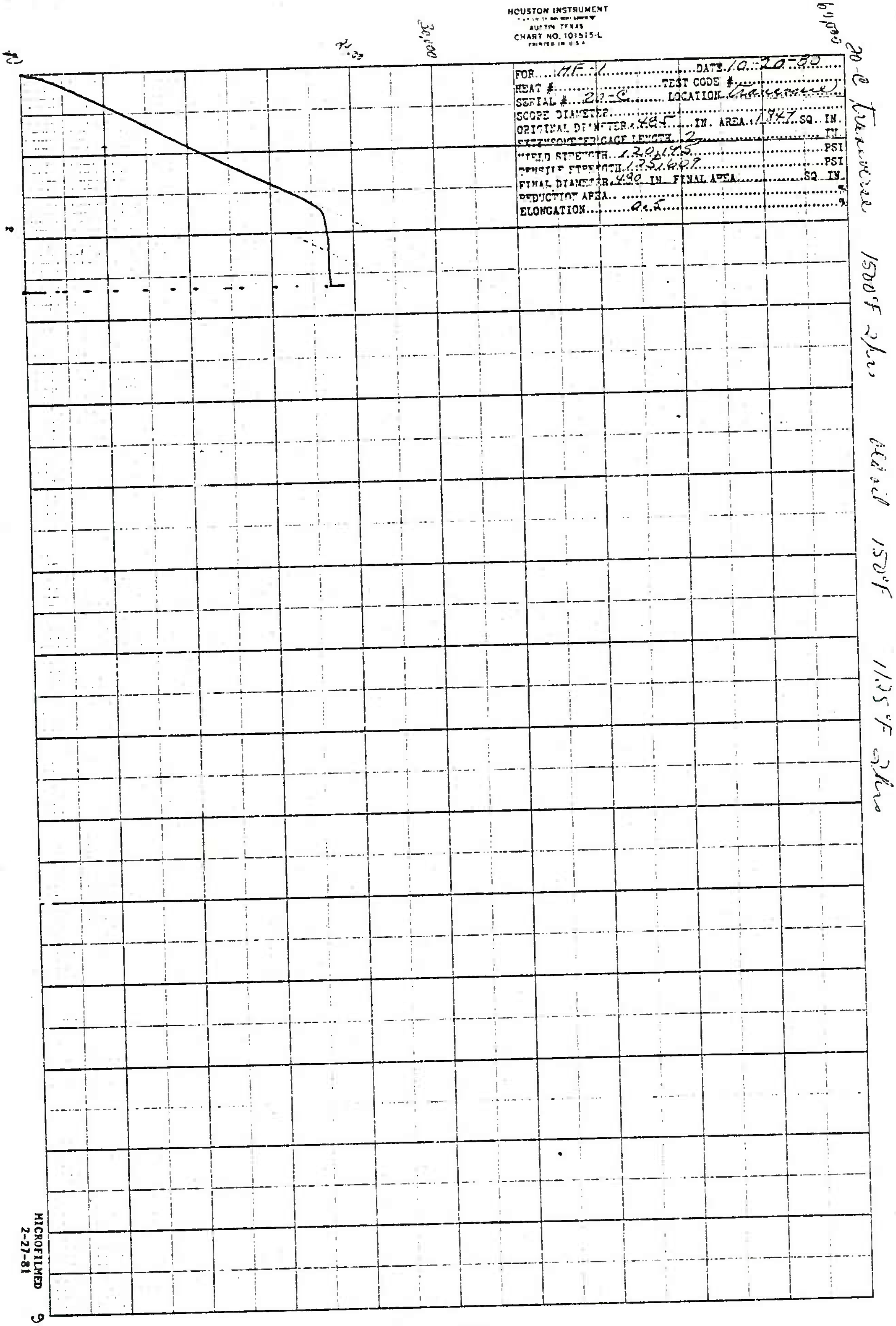

HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO 101515-L
0
30,000
60,000
FOR HF-1 DATE 9-10-80
HEAT #
TEST CODE #
SERIAL # H-T
LOCATION Long
SCOPE DIAMETER
ORIGINAL DIAMETER .504 IN. AREA .1995 SQ. IN.
EXTENSOMETER GAGE LENGTH 2" IN.
YIELD STRENGTH PSI
TENSILE STRENGTH PSI
FINAL DIAMETER IN. FINAL AREA SQ. IN.
REDUCTION AREA
ELONGATION
Rc 32.3
HF-1 H-T Long

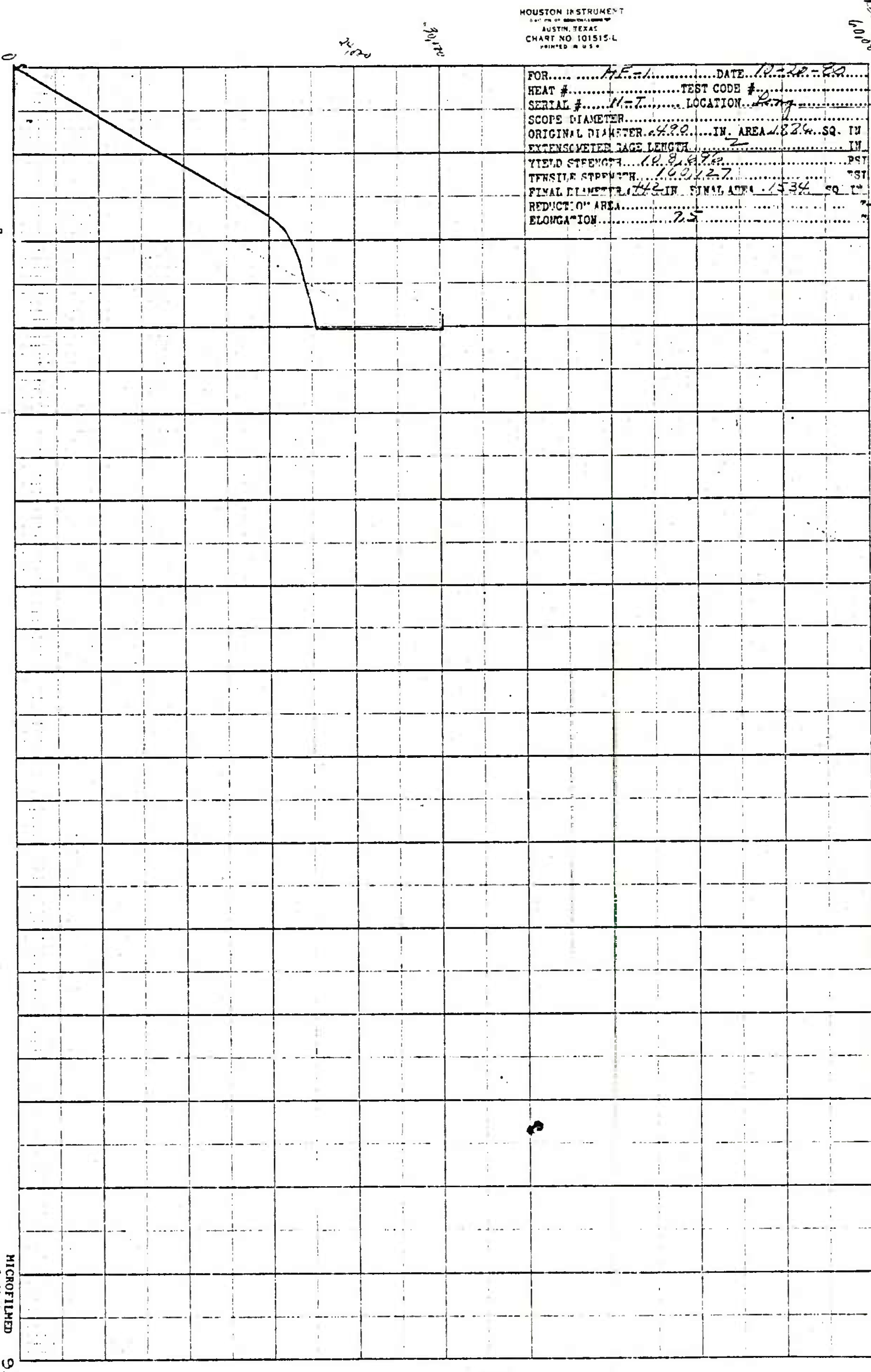
HOUSTON INSTRUMENT
AUSTIN, TEXAS
CHART NO 101565-1



MICROFILMED
7-27-81

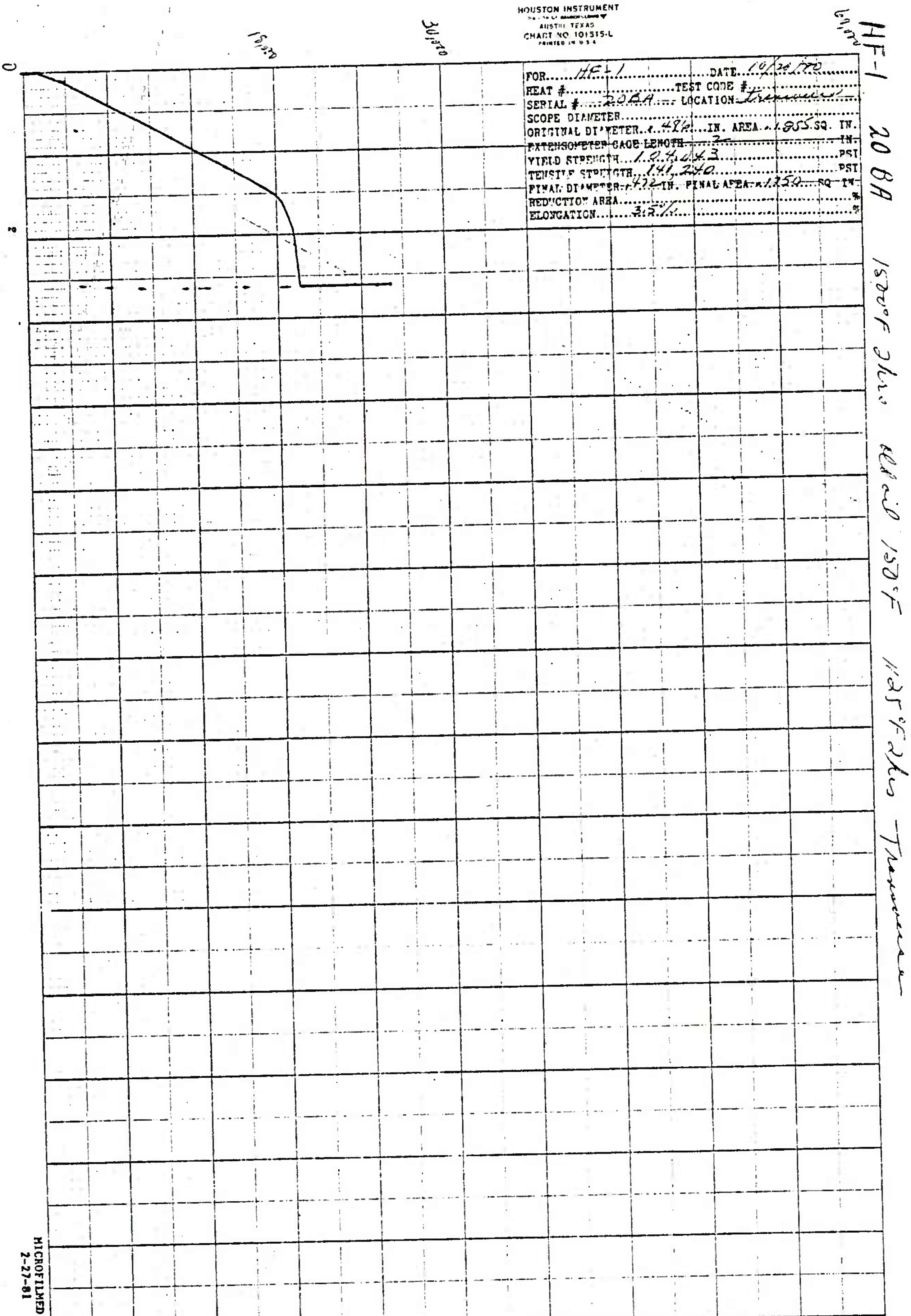
93


HOUSTON INSTRUMENT
AUSTIN TEXAS
CHART NO. 101515-L
PRINTED IN U.S.A.
30,000
60,000
FOR HF-1
DATE 10-20-80
HEAT #
TEST CODE #
SERIAL # 20-C
LOCATION Transverse
SCOPE DIAMETER
ORIGINAL DIAMETER .485 IN. AREA .1847 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 120,185 PSI
TENSILE STRENGTH 135,607 PSI
FINAL DIAMETER .490 IN. FINAL AREA SQ. IN.
REDUCTION AREA %
ELONGATION 2.5 %
20-C Transverse
1500°F 2hr
Aged 1500°F
1125°F 2hrs

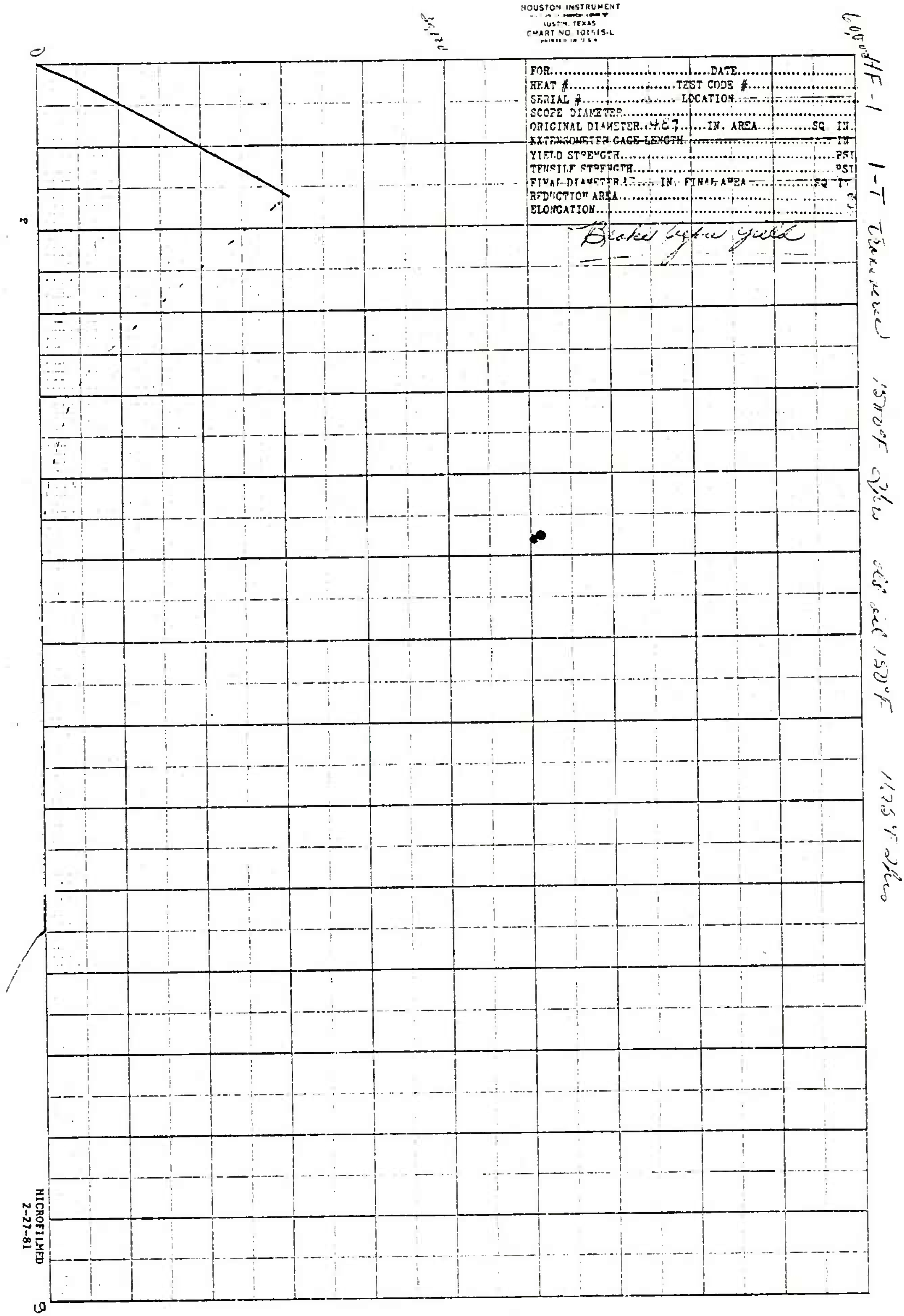


Bolt 60,000

11 T Long. 1500°F 2hrs oil 150°F 1125°F 2hrs



HOUSTON INSTRUMENT
AUSTIN TEXAS
CHART NO. 101515-L
PRINTED IN U.S.A.
0
15,000
30,000
60,000
FOR....HF-1....DATE....10/20/70
HEAT #........TEST CODE #........
SERIAL #....20BA....LOCATION....transverse
SCOPE DIAMETER........
ORIGINAL DIAMETER....486....IN. AREA....1855 SQ. IN.
EXTENSOMETER GAGE LENGTH....2....IN.
YIELD STRENGTH....104,043....PSI
TENSILE STRENGTH....141,240....PSI
FINAL DIAMETER....472 IN. FINAL AREA....1750....SQ. IN.
REDUCTION AREA........%
ELONGATION....3.5%....%
HF-1
20 BA
1500°F 3hrs
oil 130°F
1325°F 2hrs
Transverse



MICROFILMED
2-27-81

97

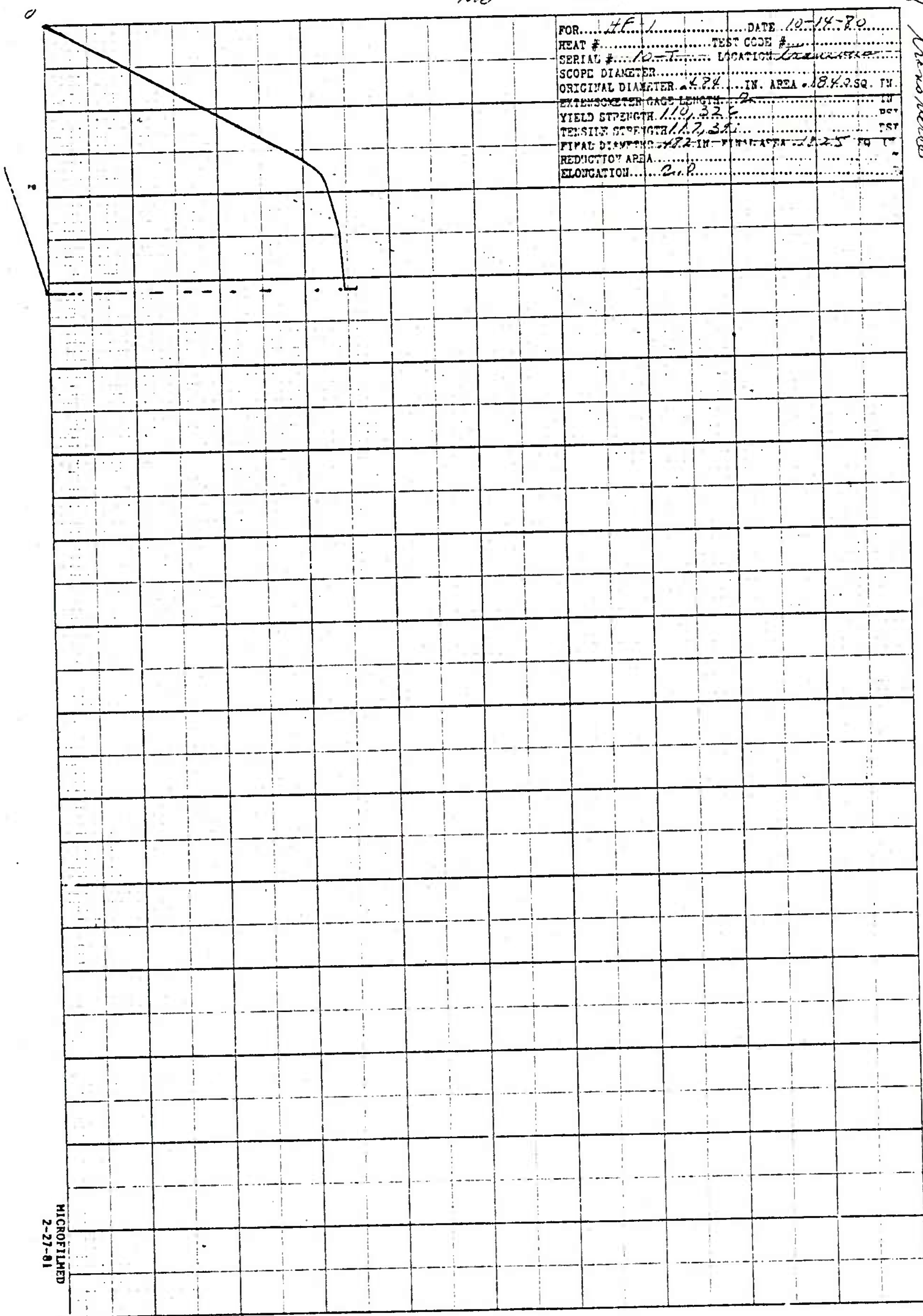
HOUSTON INSTRUMENT

AUSTIN, TEXAS

CHART NO. 101515-L

PRINTED IN U.S.A.

10-T
60,000



FOR....4E-1..........DATE 10-14-80

HEAT #..........TEST CODE #....

SERIAL #...10-T..... LOCATION Transverse

SCOPE DIAMETER..........

ORIGINAL DIAMETER. .484....IN. AREA .1840 SQ. IN.

EXTENSOMETER GAGE LENGTH...2..........IN

YIELD STRENGTH. 110,326..........PSI

TENSILE STRENGTH 117,391..........PSI

FINAL DIAMETER .482 IN FINAL AREA .1825 SQ IN

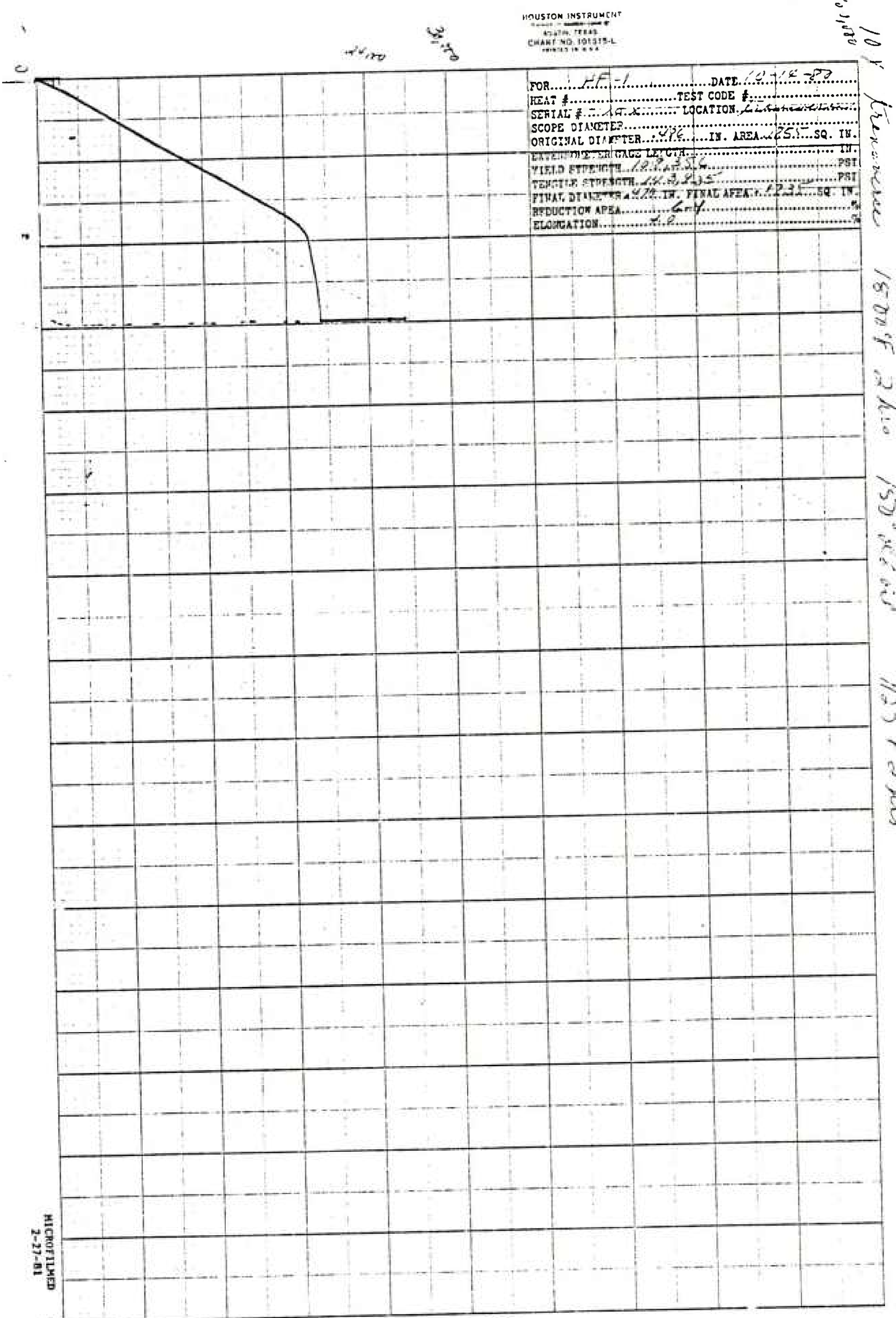
REDUCTION AREA..........

ELONGATION......2.0..........

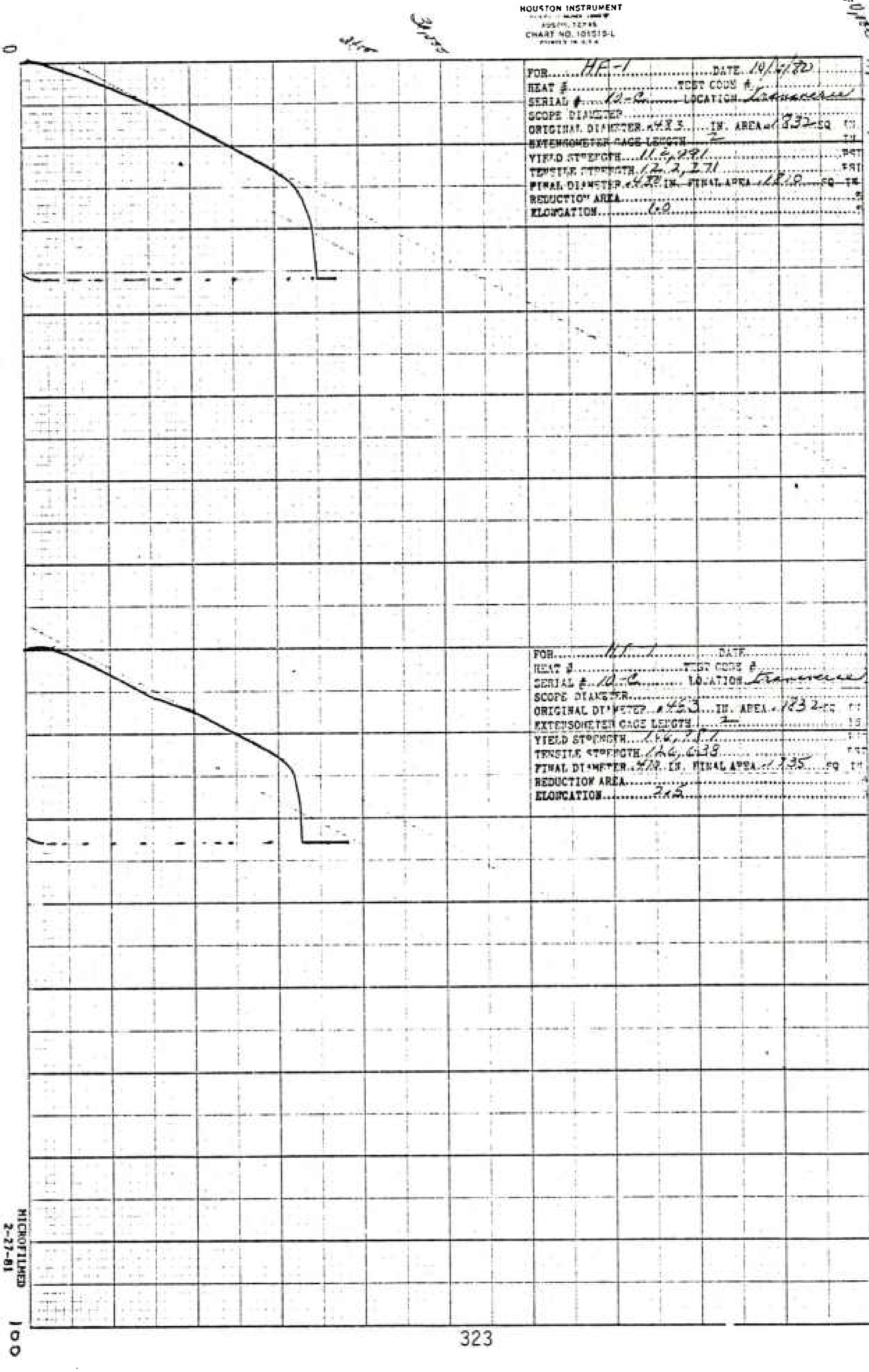
Transverse

MICROFILMED
2-27-81

98

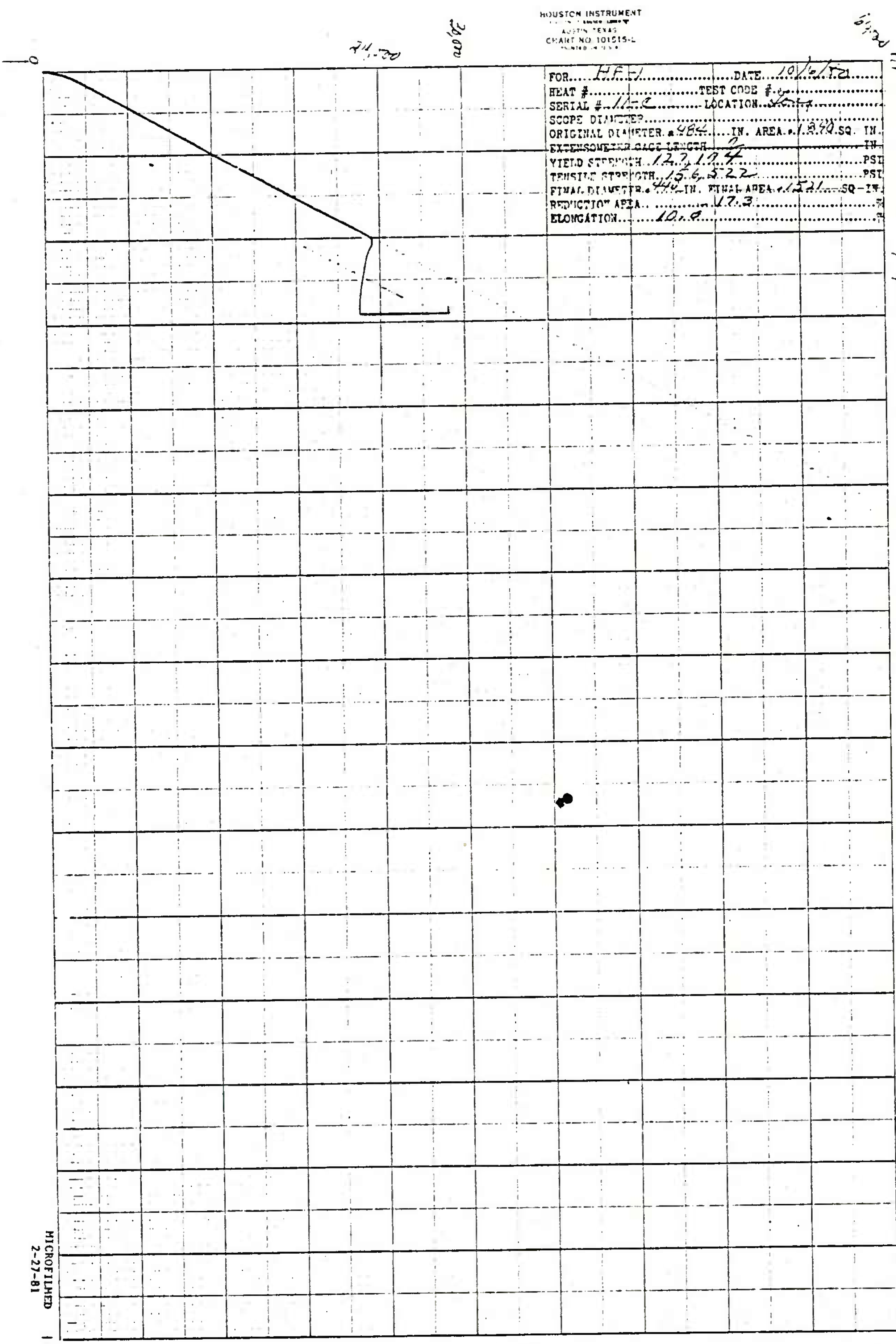


MICROFILMED 2-27-81



10-C
6090
HF-1 Transverse 1500°F 2hrs Aged 1400F 11 25 °F 2hrs

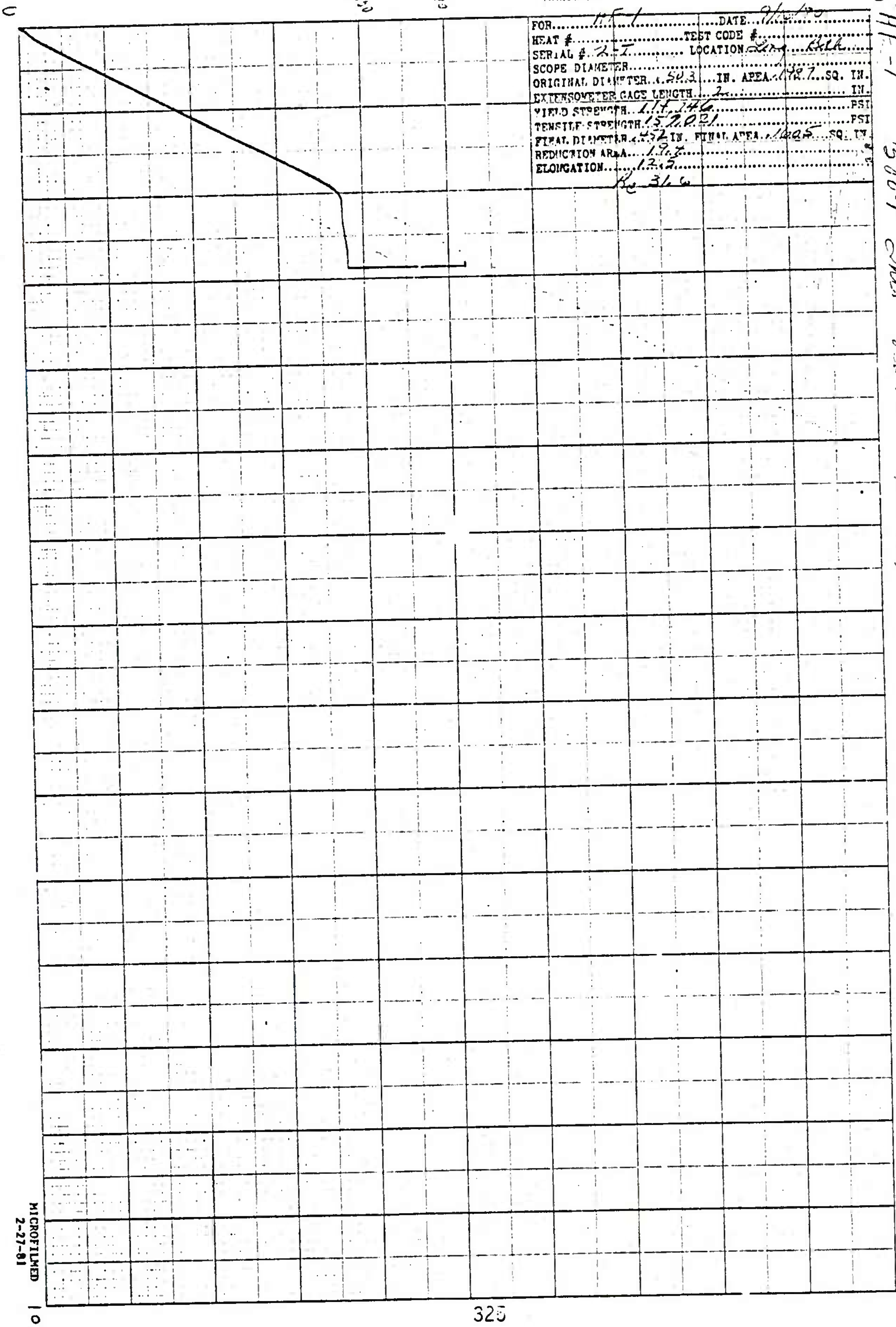
MICROFILMED
2-27-81



HF-1 11-C

1500°F 2hrs

1135°F 2hrs



FOR HF-1 DATE
HEAT # TEST CODE #
SERIAL # 2-I LOCATION Long. Bkh
SCOPE DIAMETER
ORIGINAL DIAMETER .503 IN. AREA .1987 SQ. IN.
EXTENSOMETER GAGE LENGTH 2 IN.
YIELD STRENGTH 114,146 PSI
TENSILE STRENGTH 152,021 PSI
FINAL DIAMETER .452 IN. FINAL AREA .1605 SQ. IN.
REDUCTION AREA 19.7
ELONGATION 12.5
Rc 31.6

2-7 60,000 HF-1 1500°F 3hrs OQ 1125°F 2hrs

MICROFILMED 2-27-81

102

Appendix J

Austenitic Grain Size

Austenitic Grain Size
Republic Steel

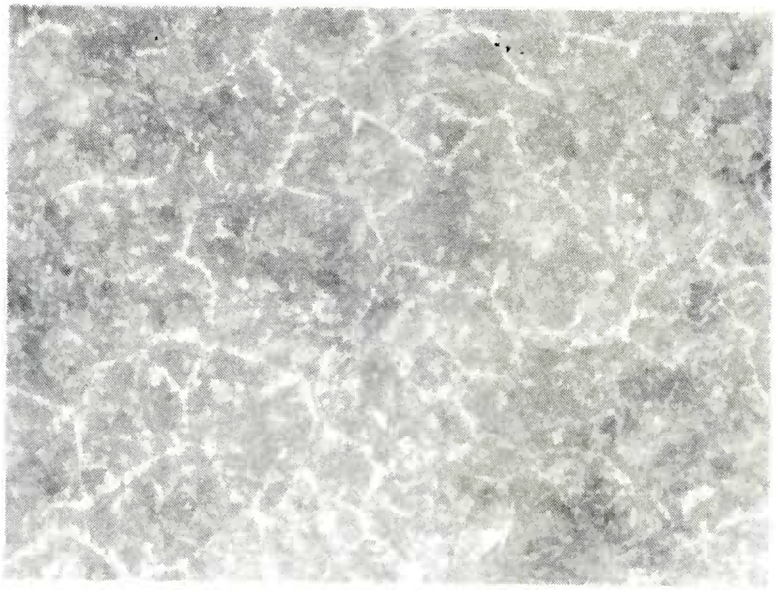


Figure J1. Billet 1AA 125x Wesley-Austin Solution

Figure J2. Billet 1BA 125x Wesley-Austin Solution

Austenitic Grain Size
Republic Steel

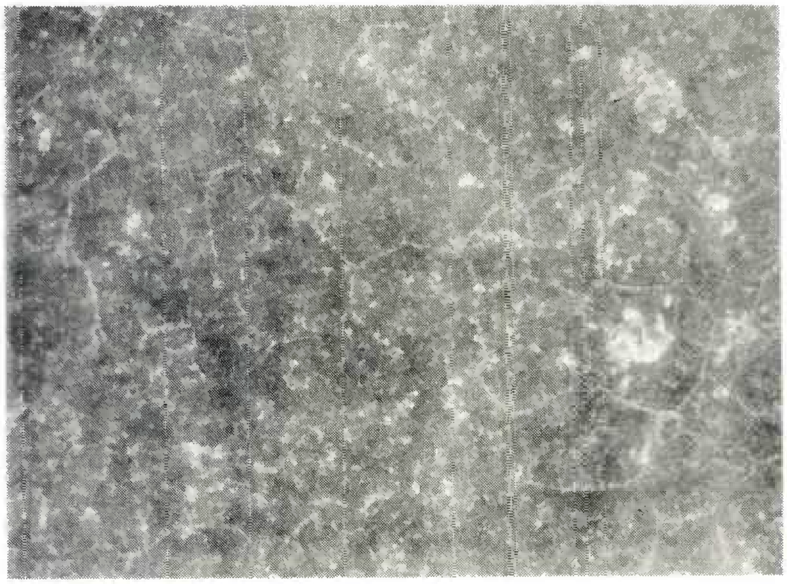


Figure J3. Billet 1BD 125x Wesley-Austin Solution

Figure J4. Billet 20AA 125x Wesley-Austin Solution

Figure J5. Billet 20BA 125x Wesley-Austin Solution

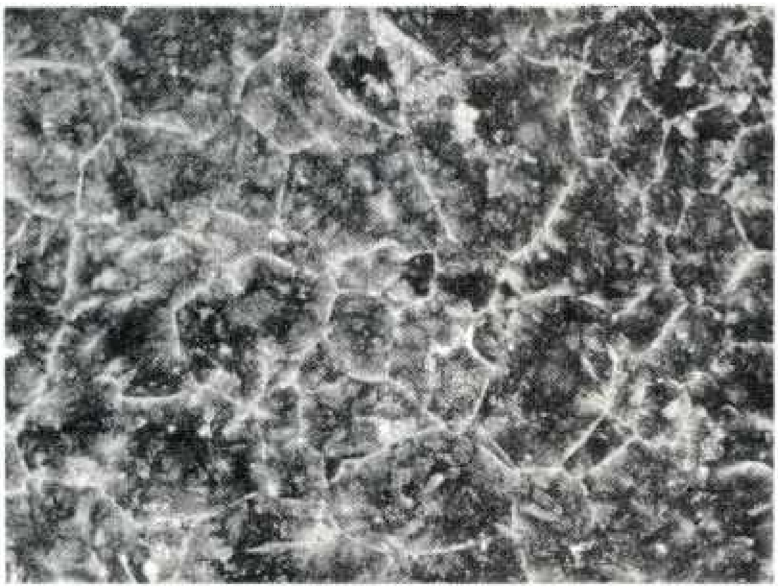


Figure J6. Billet 20BD 125x Wesley-Austin Solution

Austenitic Grain Size
Republic Steel

Figure J7. Billet 40AA 125x Wesley-Austin Solution

Figure J8. Billet 40BA 125x Wesley-Austin Solution

Austenitic Grain Size
Republic Steel

Figure J9. Billet 40BD 125x Wesley-Austin Solution

Austenitic Grain Size
Bethlehem Steel

Figure J10 Billet 1T 125x Wesley-Austin Solution

Figure J11 Billet 1C 125x Wesley-Austin Solution

Austenitic Grain Size
Bethlehem Steel

Figure J12 Billet 1X 125x Wesley-Austin Solution

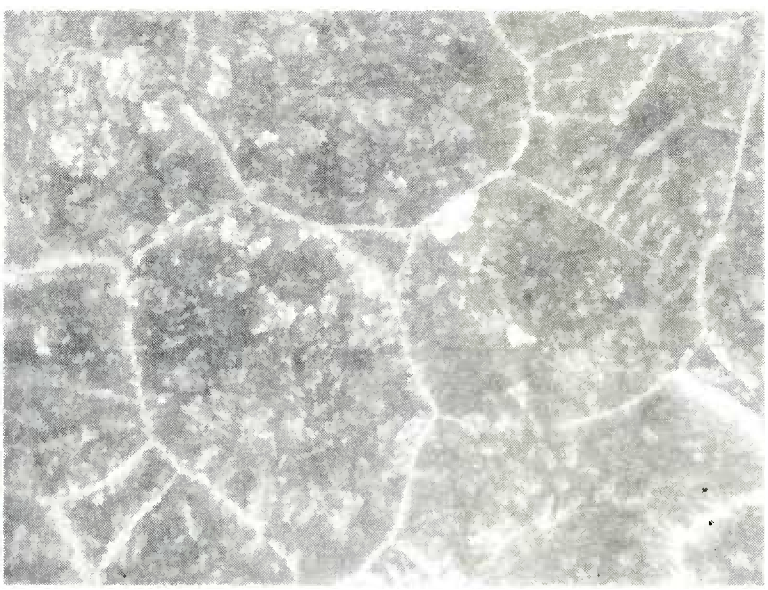


Figure J13 Billet 2T 125x Wesley-Austin Solution

Austenitic Grain Size
Bethlehem Steel

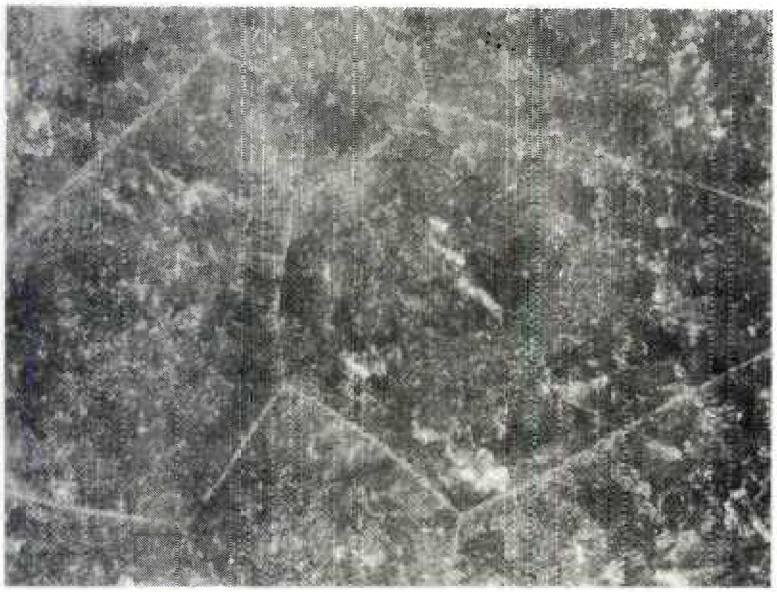


Figure J14 Billet 2C 125x Wesley-Austin Solution

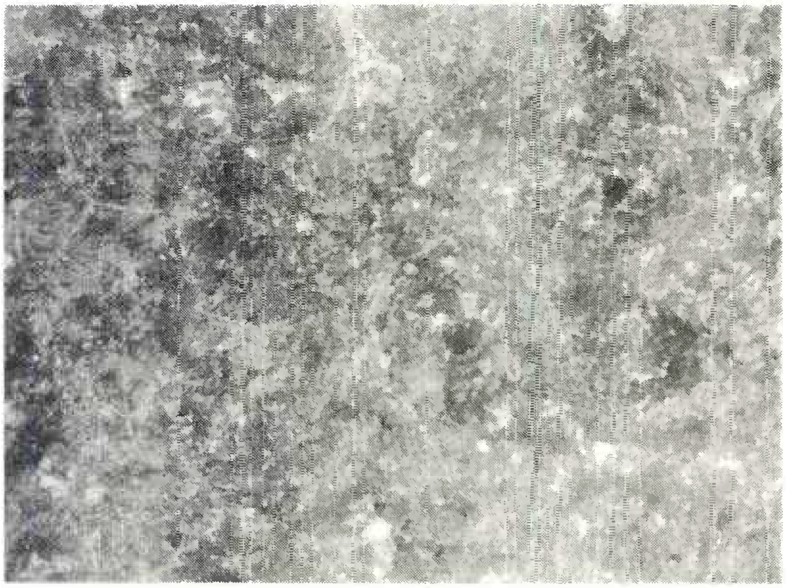


Figure J15 Billet 2X 125x Wesley-Austin Solution

Austenitic Grain Size
Bethlehem Steel

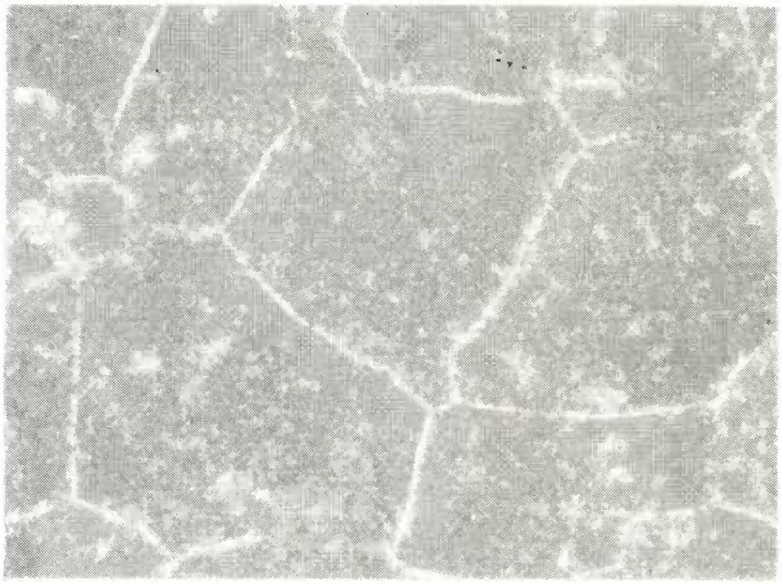


Figure J16 Billet 10T 125x Wesley-Austin Solution

Figure J17 Billet 10C 125x Wesley-Austin Solution

Austenitic Grain Size
Bethlehem Steel

Figure J18 Billet 10X 125x Wesley-Austin Solution

Figure J19 Billet 11T 125x Wesley-Austin Solution

Austenitic Grain Size
Bethlehem Steel

Figure J20 Billet 11C 125x Wesley-Austin Solution

Figure J21 Billet 11X 125x Wesley-Austin Solution

Figure J22 Billet 19T 125x Wesley- Austin Solution

Figure J23 Billet 19C 125x Wesley-Austin Solution

Austenitic Grain Size
Bethlehem Steel

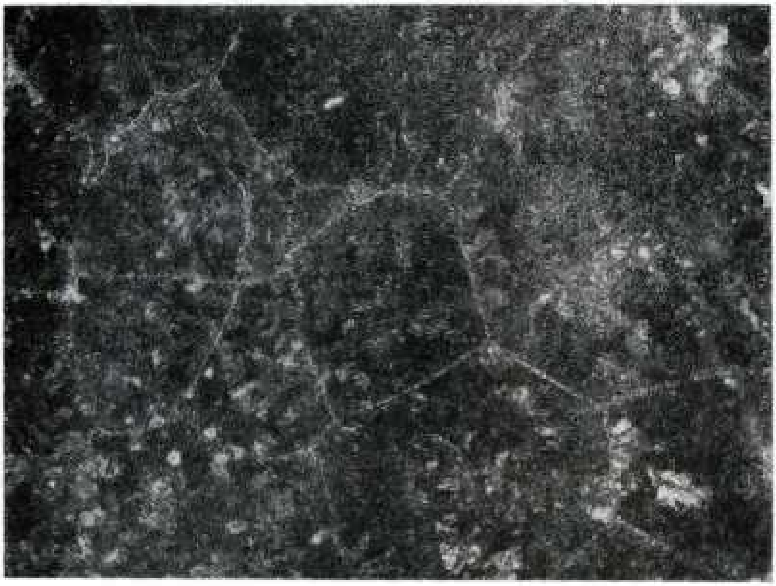


Figure J24 Billet 19X 125x Wesley-Austin Solution

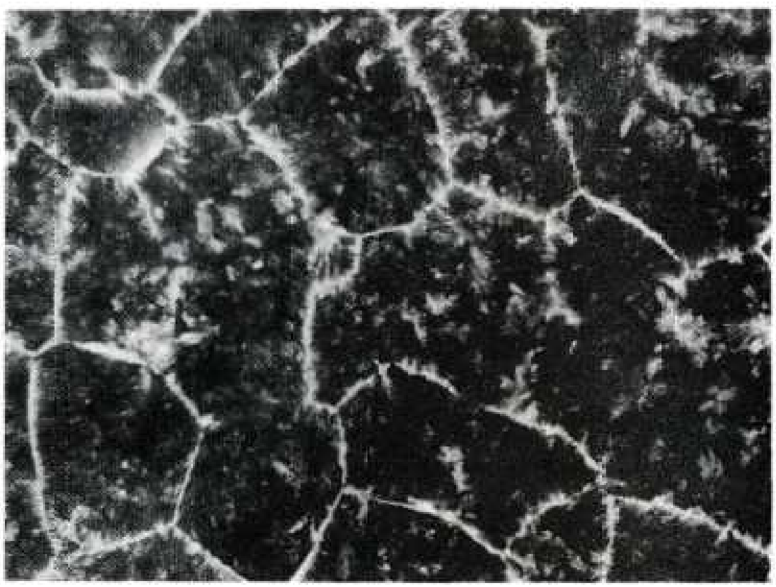


Figure J25 Billet 20T 125x Wesley-Austin Solution

Austenitic Grain Size
Bethlehem Steel

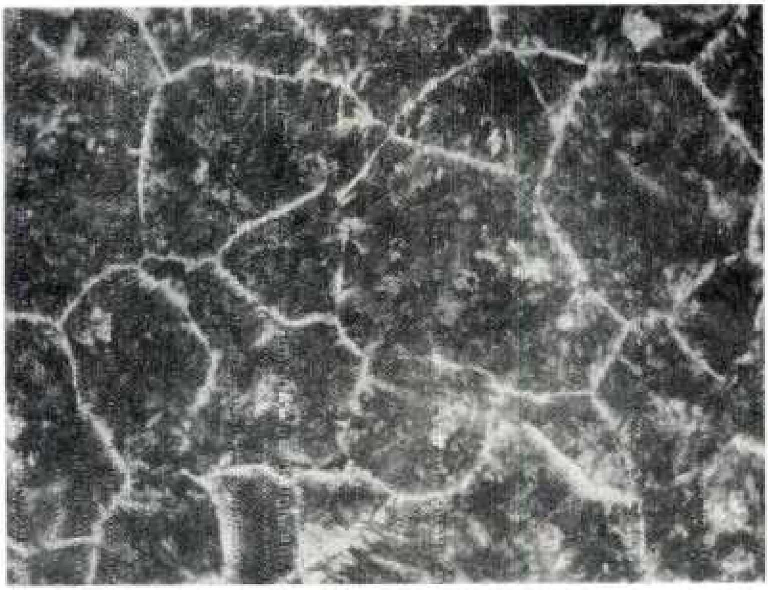


Figure J26 Billet 20C 125x Wesley-Austin Solution

Figure J27 Billet 20X 125x Wesley-Austin Solution

APPENDIX K: Etchant Formulae

1. Wesley - Austin Solution

   10 parts $H_2 SO_4$ (Sulfuric Acid)
   10 parts HNO_3 (Nitric Acid)
   10 parts H_2O (Water)

   Sample turns black and grain boundary is outlined in white, not burned.

2. 2% Nital Reagant

   2 parts HNO_3 (Nitric Acid)
   100 parts Ethanol or Methanol

3. Picral Etchant

   10 grams Picric Acid
   100 ml Ethanol (95%) or Methanol (95%)

4. Macro Etch

   50% HCl (Hydrocholoric Acid)
   50% H_2O (Water)
   at 77°C (170°F)

DISTRIBUTION

Commander
U. S. Army Armament Research and Development Command
ATTN: DRDAR-TSS (5) (Building 59)
DRDAR-CGL (1) (Building 3)
DRDAR-LCU-M (20)
DRCPM-PBM-MA (2)
DRDAR-QAR-Q (1)
Dover, NJ 07801

Administrator
Defense Technical Information Center
ATTN: Accessions Division (2)
Cameron Station
Alexandria, VA 22314

Director
U. S. Army Materiel Systems Analysis Activity
ATTN: DRXSY-MP
Aberdeen Proving Ground, MD 21005

Commander/Director
Chemical Systems Laboratory
U. S. Army Armament Research and Development Command
ATTN: DRDAR-CLJ-L
DRDAR-CLB-PA
APG, Edgewood Area, MD 21010

Director
Ballistics Research Laboratory
U. S. Army Armament Research and Development Command
ATTN: DRDAR-TSB-S
Aberdeen Proving Ground, MD 21005

Chief
Benet Weapons Laboratory, LCWSL
U. S. Army Armament Research and Development Command
ATTN: DRDAR-LCB-TL
Watervliet, NY 12189

Commander
U. S. Army Armament Materiel Readiness Command
ATTN: DRSAR-LEP-L
Rock Island, IL 61299

Director
U. S. Army TRADOC Systems Analysis Activity
ATTN: ATAA-SL
White Sands Missile Range, NM 88002